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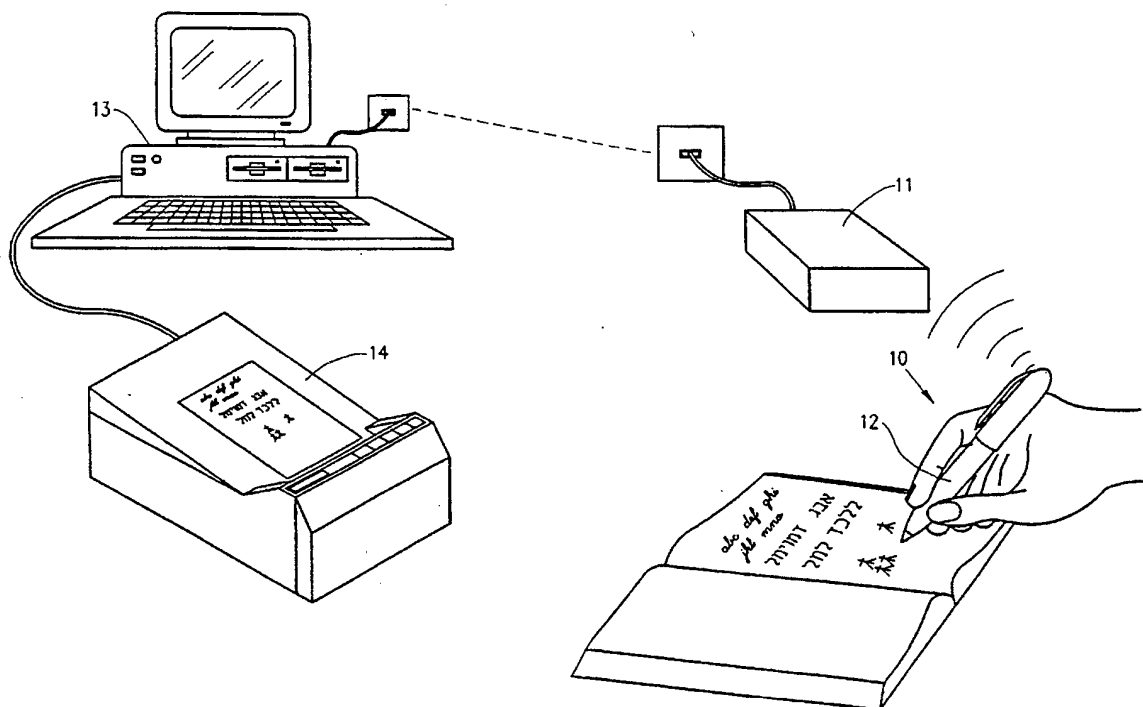
(57) Abstract

Communication apparatus for hand imaging including apparatus (11) for sensing features of hand imaging (10) of an individual which features are highly characteristic of the individual but which also contain information relating to images represented thereby and apparatus (13) for providing a non-individual dependent output (14) indicating the images in response to the sensed features.

IMAGE COMMUNICATION APPARATUS

The present invention relates to handwriting and draw-
ing communication devices generally.

There exists a significant amount of activity in the
field of on-line handwriting analysis. The prior art current to
1990 is reviewed in "The State of the Art in On-Line Handwriting
Recognition" by Charles C. Tappert et al, IEEE Transactions on
Pattern Analysis and Machine Intelligence, Vol. 12, No. 8, Au-
gust, 1990.

Generally speaking, on-line handwriting analysis is
currently employed for two distinct applications identity verifi-
cation and input of handwritten letters and numbers into a
computer. These two applications have sharply contrasting opera-
tional requirements and goals. Handwriting analysis for identity
verification senses features of handwriting which are distinct
for each individual and thus can be used to unambiguously identi-
fy a given individual. In contrast, handwriting analysis for
alphanumeric input to a computer seeks to minimize the effect of
the very features which are important for identity verification
and to concentrate on universal handwriting characteristics which
can be associated with given symbols independently of the indi-
vidual writer.

Currently existing and proposed systems providing

handwriting analysis for alphanumeric input to a computer are generally geared towards recognition of how a symbol looks rather than how it is created. Accordingly, such systems employ digitizers or graphic tablets.

Signature verification systems, on the other hand, attempt to identify biometric characteristics of the writer and employ indications such as pressure and acceleration during writing.

U.S. Patent 4,345,239 employs pen acceleration for use in a signature verification system. U.S. Patent 5,054,088 employs both acceleration and pressure data characteristics of handwriting for identity verification. As indicated by the above patents, pen acceleration is employed for signature verification because it is a personal feature, characteristic of each individual. Accordingly, pen acceleration has not been employed for communication of hand imaging.

U.S. Patent 4,817,034 describes a computerized handwriting duplication system employing a digitizer pad. U.S. Patent 4,641,354 describes apparatus for recognizing and displaying handwritten characters and figures in which unrecognized stroke information remains on the display screen. U.S. Patent 4,715,102 describes a process and apparatus involving pattern recognition. U.S. Patent 4,727,588 describes a system for automatic adjustment and editing of a handwritten text image, which preserves format information in a handwritten text. U.S. Patent 4,703,511 describes a writing input and dynamics regeneration device wherein a time dependent code is embedded in a writing

path.

The present invention seeks to provide improved hand-writing and drawing communication apparatus. For convenience and conciseness, the term "hand imaging" will be used throughout the specification and claims to denote handwriting activity as well as drawing activity and any other two or three dimensional image generating hand movements.

There is thus provided in accordance with a preferred embodiment of the present invention communication apparatus for hand imaging including apparatus for sensing features of hand imaging of an individual which features are highly characteristic of the individual but which also contain information relating to images represented thereby and apparatus for providing a non-individual dependent output indicating the images in response to the sensed features.

The phrase "non-individual dependent output" denotes an output which contains non-individual characteristics as well as, optionally, individual characteristics. Non-individual characteristics may include a geometric representation of a hand imaging product. The non-individual dependent output is typically in a form that can be communicated and read universally, for example, by any device which is capable of reading data in a standard format.

In accordance with a preferred embodiment of the present invention the apparatus for sensing is contained in a hand-held housing. Preferably the apparatus for sensing includes

apparatus for communication of the non-individual dependent output.

In accordance with a preferred embodiment of the present invention, the apparatus for communication is operative to communicate information which can be used to reconstruct an individual's hand imaging style.

In accordance with a preferred embodiment of the present invention, the apparatus for sensing does not require a tablet. Alternatively it may include a tablet. Additionally in accordance with a preferred embodiment of the invention, the apparatus for acquiring and encoding communicates via a modem. The communication may be in a fax format or alternatively in a compressed non-raster format. Preferably, the communication is wireless communication.

There is also provided in accordance with a preferred embodiment of the present invention communication apparatus for hand imaging including apparatus for sensing features of hand imaging of an individual which features are highly characteristic of the individual but which also contain information relating to images represented thereby, and apparatus for providing a non-individual dependent output indicating the images in response to the sensed features.

Additionally in accordance with a preferred embodiment of the present invention the apparatus for sensing features is contained in a hand-held housing.

Still further in accordance with a preferred embodiment of the present invention the apparatus for sensing features is contained in a tablet assembly.

Further in accordance with a preferred embodiment of the present invention the communication apparatus also includes apparatus for communication of the non-individual dependent output.

Additionally in accordance with a preferred embodiment of the present invention the communication apparatus also includes apparatus for communication of the non-individual dependent output.

Further in accordance with a preferred embodiment of the present invention the communication apparatus also includes apparatus for communication of the non-individual dependent output.

Still further in accordance with a preferred embodiment of the present invention the communication apparatus is operative to communicate information which can be used to reconstruct an individual's hand imaging style.

Additionally in accordance with a preferred embodiment of the present invention the sensing apparatus does not require a tablet.

Further in accordance with a preferred embodiment of the present invention the apparatus for communication includes a modem.

Still further in accordance with a preferred embodiment of the present invention the apparatus for communication is operative to communicate in a fax format.

Additionally in accordance with a preferred embodiment of the present invention the apparatus for communication is

operative to communicate in a compressed non-raster format.

Further in accordance with a preferred embodiment of the present invention the apparatus for communication is operative for wire communication.

Still further in accordance with a preferred embodiment of the present invention the apparatus for communication is operative for wireless communication.

Additionally in accordance with a preferred embodiment of the present invention the apparatus for sensing features includes apparatus for sensing the instantaneous angle of motion during hand imaging.

Further in accordance with a preferred embodiment of the present invention the apparatus for providing a non-individual dependent output is operative for providing an output indication of strokes generated during hand imaging.

There is also provided in accordance with another preferred embodiment of the present invention communication apparatus for hand imaging including apparatus for sensing features of hand imaging of an individual which features are highly characteristic of the individual but which also contain information relating to images represented thereby, and apparatus for providing an output indicating the images in response to the sensed features, and wherein the apparatus for sensing features including apparatus for sensing the instantaneous angle of motion during hand imaging and providing an output indication of strokes generated thereby.

There is also provided in accordance with another preferred embodiment of the present invention apparatus for

communicating hand imaging including hand-held apparatus for
sensing motion and providing an output in a compressed form which
can be transmitted by a conventional modem, LAN or other communi-
cations medium.

Further in accordance with a preferred embodiment of
the present invention the apparatus includes apparatus for re-
ceiving communicated stroke content information and being opera-
tive for reconstructing therefrom hand-imaging information.

Still further in accordance with a preferred embodi-
ment of the present invention the apparatus for receiving is
operative to reconstruct hand-imaging information in three dimen-
sions.

There is also provided in accordance with another
preferred embodiment of the present invention communication
apparatus for hand imaging including apparatus for sensing motion
during hand imaging and providing an output indication of stroke
content in a compressed format, and apparatus for receiving
communicated stroke content information and being operative to
reconstruct therefrom hand-imaging information.

Further in accordance with a preferred embodiment of
the present invention the apparatus for receiving is operative to
reconstruct hand-imaging information in three dimensions.

There is also provided in accordance with another
preferred embodiment of the present invention a communication
method for hand imaging including sensing features of hand
imaging of an individual which features are highly characteristic
of the individual but which also contain information relating to

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images represented thereby, and providing a non-individual de-pendent output indicating the images in response to the sensed features.

There is also provided in accordance with another preferred embodiment of the present invention a communication method for hand imaging including sensing features of hand imag-ing of an individual which features are highly characteristic of the individual but which also contain information relating to images represented thereby, and providing an output indicating the images in response to the sensed features, and wherein the sensing features includes sensing the instantaneous angle of motion during hand imaging and providing an output indication of strokes generated thereby.

There is also provided in accordance with another preferred embodiment of the present invention a method for commu-nicating hand imaging including hand-held apparatus for sensing motion and providing an output in a compressed form which can be transmitted by a conventional modem, LAN or other communications medium.

There is also provided in accordance with another preferred embodiment of the present invention a communication method for hand imaging including sensing motion during hand imaging and providing an output indication of stroke content in a compressed format, and receiving communicated stroke content information and reconstructing therefrom hand-imaging informa-tion.

The present invention will be understood and appreciat-
ed more fully from the following detailed description, taken in
conjunction with the drawings in which:

Fig. 1 is a pictorial illustration of a device for
acquiring and encoding hand imaging which is constructed and
operative in accordance with a preferred embodiment of the
present invention in an operative environment;

Fig. 2 is a simplified illustration of a preferred
structure of the acquiring and encoding device of Fig. 1;

Fig. 3 is a pictorial illustration of another device
for acquiring and encoding hand imaging which is constructed and
operative in accordance with a preferred embodiment of the
present invention in an operative environment;

Fig. 4 is a simplified illustration of a preferred
structure of the acquiring and encoding device of Fig. 3;

Figs. 5A and 5B are pictorial illustrations of a pocket
held communicator unit and pen incorporating the apparatus of
Figs. 1 and 2;

Fig. 6 is a simplified illustration of apparatus for
communicating and reconstructing three-dimensional hand imaging
information in accordance with a preferred embodiment of the
present invention.

Attached herewith are the following appendices which
aid in the understanding and appreciation of the invention shown
and described herein:

Appendix A is a detailed exposition of the findings of

the inventor concerning the characterization of hand imaging via pen strokes;

Appendix B is a computer listing comprising a preferred implementation of a portion of the programming of microcontroller 26;

Appendix C is an explanation of the computer listing of appendix B;

Appendix D is a computer listing comprising a preferred implementation of a portion of the programming of microcontroller 46;

Appendix E is an explanation of the computer listing of appendix D;

Appendix F is a computer listing comprising a preferred implementation of a portion of the programming of computer 13;

Appendix G is an explanation of the computer listing of appendix F;

Appendix H is a computer listing comprising a preferred implementation of a portion of the programming of computer 13; and

Appendix I is an explanation of the computer listing of appendix H.

It has been found by the present inventor that each writer produces conventional alphanumeric characters as well as graphic images, i.e. hand imaging, from pen strokes selected from a set containing approximately 12 - 14 pen strokes which set is characteristic of each individual. The present invention employs this realization to provide communication apparatus for hand imaging. Appendix A contains a detailed exposition of the finding of the inventor.

Reference is now made to Fig. 1, which illustrates a pen for communicating hand imaging 10 constructed and operative in accordance with a preferred embodiment of the invention in a typical operating environment wherein it communicates by wireless communication with a communicator 11, such as a telephone or RF modem having an associated receiver, such as a model RB 1023 RF receiver, commercially available from RF Monolithics, Inc. of Dallas, Texas. Alternatively, communication may be effected via any other suitable communications medium such as, for example, a local area network and a cellular telephone network.

The hand imaging communicating pen 10, which is illustrated in greater detail in Fig. 2, may be used on any writing surface or alternatively in the absence of a writing surface and does not require any special pad or writing substrate. Preferably the handwriting input device comprises a housing 12 in the general size and shape of an ordinary pen.

Communicator 11 may communicate via telephone or coaxial cabling or wireless facilities with any suitable receiver,

such as a computer terminal 13 having an associated printer 14.
Thus it may be appreciated that the hand imaging produced by the
user using apparatus 10 may appear nearly instantaneously on a
printed hard copy or a computer screen at a remote location. The
same general type of apparatus may be employed for display on a
television screen or for output on a facsimile receiver.

As seen in Fig. 2, disposed in housing 12 is an ink
reservoir and output point assembly 16, which may be constructed
and operative in any conventional manner. Alternatively no ink
output may be provided. In accordance with a preferred embodiment
of the present invention there is disposed in a forward location
of the housing 12 an accelerometer 20, preferably operative in
three dimensions. A typical accelerometer which meets the size
and power requirements of the invention comprises three mutually
orthogonally mounted Model 3031-002 accelerometers commercially
available from EuroSensor of 20 - 24 Kirby Street, London, Eng-
land. Alternatively, more than 3 Model 3031-002 accelerometers
may be used.

The output of the accelerometer 20 is supplied via an
operational amplifier 24, such as a model LT1179, commercially
available from Linear Technology Corporation of Milpitas, Cali-
fornia, to a microcontroller 26, such as an Hitachi H8/536 micro-
controller including an A/D converter. Microcontroller 26 is
operative to extract a plurality of predetermined features of the
acceleration sensed by accelerometer 20. It is a particular
feature of the present invention that a relatively small number
of discrete features derived from sensed acceleration during hand
imaging has been found to be sufficient to map the alphanumeric

symbols and graphic output of a given individual. It is appreci-
ated that the characteristics of such features vary from individ-
ual to individual and it is often desirable to communicate these
personal characteristics. Accordingly, the microcontroller 26 is
programmed in order to preserve and communicate not only the
information content but also the personal hand imaging character-
istics of the writer.

A preferred listing in the C programming language of
software that provides the functionality of the microcontroller
26 appears in Appendix B. A brief discussion of the principles
underlying the functionality of the microcontroller 26 as exem-
plified in the software of Appendix B, appears in Appendix C.

The microprocessor 26 is operative to extract a plural-
ity of strokes and to encode them in a conventional universal
code, such as ASCII, which is not in any way dependent on the
personal handwriting characteristics of a given individual and
which can be readily accepted by conventional computers, modems
and the like.

Preferably, the coded symbol output from microcontrol-
ler 26 is in a form compatible with or identical to the output
conventionally received from or modem input to a conventional
computer, such as a PC.

In accordance with a preferred embodiment of the
present invention, the coded output of microcontroller 26 is
transmitted to communicator 11 in a wireless manner by a wireless
transmitter 32, such as a model MB1003, which is also commercial-
ly available from RF Monolithics, Inc. and which communicates

with receiver 12 (Fig 1). Alternatively any other suitable IR transmitter or radio transmitter may be utilized.

Alternatively a non-wireless communication connection may be provided as described hereinbelow with reference to Figs. 5A and 5B. In such a case, a non-volatile memory such as a flash RAM 34 is preferably provided to store the output of the micro-controller 26. A suitable battery 33 is provided to power the apparatus located within housing 12.

It will be appreciated that the apparatus of the present invention is preferably a hand-held "pen" which can be carried by a user and used with any suitable communication facilities. The communication facilities and computers as well as peripherals communicating therewith need not be personalized in any way, inasmuch as all of the handwriting recognition hardware and software is resident in the "pen".

Reference is now made to Figs. 3 and 4 which illustrates an alternative embodiment of the present invention which employs a tablet assembly 40 instead of pen 10. The tablet assembly 40, as seen in Fig. 4, may comprise any conventional graphic input tablet 42, such as a Summagraphics compatible tablet which operates together with a dedicated pen 44 and which outputs x,y coordinates and pen lift signals to a microcontroller 46.

Microcontroller 46 may have all of the relevant functionality of microcontroller 26 described hereinabove for stroke extraction and encoding and may communicate directly with a modem/fax unit 48, such as is commercially available from Rockwell and other suppliers. A preferred listing in the C programming language of software that provides the functionality of the

microcontroller 46 appears in Appendix D. A brief discussion of the principles underlying the functionality of the microcontroller 46 as exemplified in the software of Appendix D, appears in Appendix E.

The output of modem/fax unit 48 may be connected to an ordinary telephone or network jack 50 for communication in the manner described hereinabove in connection with Fig. 1.

Appendix F sets forth a software listing in the C programming language for reconstruction functionality of the information communicated by the tablet assembly 40. This software may be resident in computer 13 or alternatively in any output device whose function it is to provide a useful output from the communicated hand imaging information. Appendix G is a brief discussion of the principles underlying reconstruction functionality embodied in the listing of Appendix F.

Appendix H sets forth a software listing in the C programming language for reconstruction functionality of the information communicated by the pen 10. This software may be resident in computer 13 or alternatively in any output device whose function it is to provide a useful output from the communicated hand imaging information. Appendix I is a brief discussion of the principles underlying reconstruction functionality embodied in the listing of Appendix H.

Further in accordance with a preferred embodiment of the present invention there is provided portable information storage and retrieval apparatus including a portable computer memory and output device and having as an input element hand-held

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apparatus of the type described hereinabove.

Reference is now made to Figs. 5A and 5B which illus-
trate acquisition and encoding apparatus for hand imaging and
communication apparatus in accordance with an alternative embodi-
ment of the present invention. Here a communicator 100 is formed
with a socket 101 for removably accepting acquisition and encod-
ing apparatus 102. Data communication contacts 104 and 106 are
disposed respectively at an end of the apparatus 102 and in
socket 101 for permitting downloading of written information from
apparatus 102 to the communicator 100. Preferably the communica-
tor is designed to be pocket sized.

Reference is now made to Fig. 6, which illustrates the
use of the apparatus of the invention for communicating three
dimensional information. A user employing the apparatus outlines
the shape of a three dimensional object, such as an airplane
model. The user may follow the lines of an existing three dimen-
sional model, as in the illustration, or alternatively, may draw
in a free hand manner. The hand imaging produced by the user is
communicated via communicator 11 to a communicator 120 and thence
to utilization apparatus such as a CNC machine 122 or a three
dimensional model building machine 124, such as is commercially
available from Cubital Ltd. of Ramat Hasharon, Israel.

Communication of hand imaging information in accordance
with the present invention may be in two different modes. Where
compression is desired along the communication channels, the hand
imaging information may be transferred in a penstroke language.
In such a case, a hand imaging reconstructor is required at the
remote location.

Alternatively, the hand imaging information can be reconstructed upstream of communicator 11, by suitable recon-struction apparatus. In such a case, the hand imaging information may be communicated in conventional CAD format.

It will be appreciated by persons skilled in the art that the present invention is not limited by what has been par-ticularly shown and described hereinabove. Rather the scope of the present invention is defined only by the claims which follow:

APPENDIX A

What the human brain tells the human hand
A behavioral perspective

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September 22, 1992

Abstract

This study investigates the primitives of motoric patterns of hand movement during handwriting. This is referred to as the "language" between the "hand and the "brain", and as such, has its own vocabulary and syntax. The "vocabulary" is the pen strokes and the syntax is how they are combined to pen strokes sequences. The handwriting is viewed as a high level cognitive activity of communicating, expressed as a complex motor skill and its investigation provides insight into the processes of chunking and automaticity. The main finding of this study is that pen strokes are specific to an individual writer, and characterize the writer's unique motoric control mechanism. The dynamic data of many thousand handwritten characters, produced by many writers, had been analyzed. The time domain signals were segmented into discrete pen strokes units and represented as vectors in a feature space. Those vectors were clustered, using a variety of clustering techniques. We found that in spite of the fact that the hand movements during writing could take any form or shape, a particular writer employs only a very limited set of pen strokes. The results of the clustering by various methods, yields a limited set of only twelve to fourteen types of pen strokes that accounts for 90brain supposedly chunks information to minimize the required attentional resources.

1   Humans motor behavior

When we speak about "what the human brain tells the human hand", we
speak about the kind of "motor control language", that might exist between
the "brain" and the "hand". While this "brain-hand" communication can
be approached from different points of view, we study it from a behavioral
perspective. That is, we investigate the evidence of chunks or what is referred
to as "motor programs", by analyzing the dynamic data collected during
experiments in hand-writing recognition. Although all the results reported
in this article consists only on the output of the handwriting process, we try
to make the proposed model cognitive and biological plausible. ·

We'll start with the cognitive plausibility. There is a strong link between
cognitive mechanisms and the human motor behavior. Handwriting is the
way that humans express their thoughts through the use of a complex motor
skill. Rosenbaum [12], presented handwriting as culmination of several in-
ternal translation process. First, an abstract message or idea is constructed.
Then, it is formulated into appropriate linguistic expression, and then trans-
lated as a series of efferent commands. There is a basic similarity between
speech and writing, so we can assume that both share the same underlying
mechanism. The phonemes in speech, correspond to pen-strokes in writing,
and the morpheme in speech correspond to letters. The higher levels of ab-
straction (i.e. words, syntax, lexicon, semantics, prosody and discourse), are
probably the same.

There is an empirical evidence, that the ability to sequence behavior,
whether in the linguistic domain or drawing domain, depends on a central,
amodal mechanism [11]. If this is true, then motoric control should be consid-
ered as obeying the same rules of the linguistic or other sequential cognitive
mechanisms. On the other hand, some of the properties that we discover
about the primitives of the motor control language, might be generalized to
other cognitive activities. In the case of handwriting, the efferent commands
are expressed as pen-strokes. It was found by Wright [17], that different pro-
duction mechanism are probably controlled by the same high-level graphic

representation. This view of hierarchical structuring, and a "virtual" representation of motor movement is supported by empirical evidence. Humans can write in a consistent style when they write in small letters in their notebooks, or when writing much bigger characters on a blackboard. Moreover, people can write with a consistent style (same pen-strokes), when using different effectors like hand and foot.

As in any behavioral research, resulting behavior is influenced both by the general properties of handwriting and by properties which are specific to an individual writer. This means that a considerable part of the variance can be attributed to individual differences. It has been noticed by many researchers that handwriting style is so distinctive, that writers can be recognized according to their hand writing. This is also a common knowledge, and therefore signatures are recognized as a unique identifier of a specific writer. Some theories even associate personality traits with hand-writing style. As we intend to show in this article, the primitive pattern of writing, are unique for individuals writers.

As any other cognitive or motor activity, human motor control goes through a process of development that is equivalent to intellectual development. An interesting well known phenomena is that children's drawing (and after that writing), becomes more refined over the course of development. It has been suggested by many researchers, that early drawing behavior correlates with young children's cognitive abilities. Van sommers [15], suggested that drawing may be governed by high-level rules, similar to those governing language processing, and that the development in drawing may parallel the development of language. Goodnow and Levine [9] even suggested a: "Grammar for action: sequence and syntax of children's copying." They reported several rules for sequencing drawing strokes. Examples of such rules were:" Start at leftmost point", "Start at top", "Start with vertical strokes". "draw horizontal lines from left to right", etc. The evolutionary rationale for such rules could be to simplify motor planning.

The biological plausibility of an hand writing model, involves two parts: The plausibility of the assumed neurological control, and the biomechanical properties of the hand. The preservation of the writing style while using different muscles and even organs, is one of the most intriguing questions. The automaticity of writing, suggests a chunking mechanism, but this chunking mechanism is probably not in the motoric system of the hand, but somewhere in the upper control levels of the brain. Therefore, whenever we refer to

the "hand", we do it metaphorically. I.e. the "hand" represents the efferent
mechanism that accomplishes the motoric control. Recently, Alexander et al.
[3], raised the question whether the specific concept of a "motor program", is
an appropriate foundation for the development of biological plausible models
of how the brain controls movements. While our current knowledge about
the cortical and basal ganglia motor areas is still far from allowing a specific
model, it can suggest what models are more neurologically plausible than
others. Fischbach [7] discusses the finding about "face cells" and "motor
command cells" as an evidence for abstraction in the brain. In the monkey's
visual system, "face cells" located in the inferior temporal sulcus, were sug-
gested as representing a high level of abstraction. These neurons respond to
faces but not to other visual stimuli. Face cells have their counterparts on the
motor side. "Command" neurons have been identified in certain vertebrates
that trigger fixed action patterns. Georgopolos [1] recorded electrical activ-
ity of single neurons, and found command neurons in the monkey's motor
cortex (precentral gyrus) that encode the direction of forelimb movement.
The firing of these neurons was not associated with the contraction of a par-
ticular muscle or with the force of the coordinate movement. Georgopoulos
computed a vector by summing the firing frequencies of many neurons, and
found that it is more correlated with the direction of movement than is the
activity of any individual cell. The vector becomes evident several millisec-
onds before the arm moves. He interpreted this result as evidence for motor
neuron planing. Damasio and Damasio [4] discussed the linguistic behavior
of patients with lesion in the left posterior temporal and inferior parietal cor-
tex. It was found that such patients have problem in producing word forms
from the available phonemes. Analyzing the accumulated empirical finding
on language structures, gathered with assistance of imaging techniques like
MRI (Magnetic Resonance Imaging) and PET (Positron Emmision Tomog-
raphy), shows that linguistic activity like naming, involves the motor cortex
activation together with anterior and posterior language centers in the left
hemisphere. Writing is a language activity which involves a production cen-
ter that forms words and activates the "command cells" in the motor cortex
to produce pen-strokes sequences (letters) and written words. In the same
way that speech is composed of a small set of phonemes, we argue that
handwritten letters are composed of a small set of pen-strokes.

In addition to the neurological plausibility, there are biomechanic con-
straints on the "hand" part. Some general principles have been suggested

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as governing this control mechanism. For example. Flash and Hogan [8], proposed that humans tend to write in a way that minimizes *jerk*. That is, the third time derivative of the position signal. A more recent study [6], suggested the *snap*. which is the fourth derivative of position, as the cost function that is minimized. As we will see, there are alternative hypotheses about the type of constraints imposed on the biomechanics of handwriting. In spite of the fact that the principle that governs the handwriting might be universal, each writer has its own unique variation. The differences are more pronounced in the unwritten strokes (the pen movements that do not touch the writing surface0 than in the written ones. The friction of the pen with the writing surface diminishes the characteristics of the hand control mechanism which are better revealed when the pen is up.

The article starts with reviewing theories of "motor programs". and arguing against that term and what it implies. We'll propose an alternative connectionist model of primitive hand-writing patterns and argue that it is more biologically and cognitive plausible. Then, we describe the experiment, and the collection of the data. The fourth chapter will describe the analysis of the collected data, and the conclusions that were drawn from this analysis. The last chapter will discuss the results, and compare our conclusions to alternative ones. We shall conclude the article by pointing out some future directions and implications of the suggested model.

2   Attention, chunking and "motor programs"

The concept of "working memory" is modeled after the "working memory" in a (von Neumann) computer, where the registers in the Central Processing Unit (CPU) have a similar function. This is also why researchers in that field prefer to talk about "motor programs". "Motor programs" are supposed to save attentional resources. According to this approach, it is assumed that the brain controls movements like handwriting. by executing "motor-programs", much like software is used in a computer (e.g. [12]). The "motor program" concept is attractive, as it reduces the complexity of the sequential, analytical approach by using pre-programmed sequences of a limited number of generic motor commands (or routines), to control a large repertoire of movements. Alexander et al. [3] points out difficulties with the neurological plausibility of "motor programs" that imply separation between "software"

and "hardware". For example. what would constitute the software in such a model. and where it is stored when not executed. how are they assembled prior to their execution and how new programs are created. A major problem with the "motor program" approach is also the sequencing of performance: goal- directed movements are supposed to be translated into trajectories, then to joints kinematics. Muscle activation cannot be computed until the inverse dynamics is calculated and so on. Therefore. argue Alexander et al., signs of specialization for such transformations should have been found in the cortical and basal ganglia. Thusfar. neurobiological evidence seems to indicate lack of such specialization.

It is assumed that the processing capacity is limited, and therefore several tasks that have to be carried out simultaneously compete on the same resources. The main "problem" of human-beings and other organism might be, that we lack a "parallel output channel". All the output channels. be it speech, handwriting or any other motor output, are all serial in nature. It might be that this serial output suggested a serial cognitive mechanism as well. It is the conjecture of the neural-nets literature. and of this article, that the underlying mechanism is parallel and distributed over millions of simple processing units (neurons). Therefore. the term "motor programs". that implies a serial symbolic process running in the "brain-computer" might be misleading. We prefer to speak about "motoric schemas", which are motoric patterns invoked by activation of an assembly of neurons.

The connectionist view of schemas (Smolensky. 1986) is that stored knowledge-atoms are dynamically assembled at the time of inference, into context-sensitive schemata. Rumelhart and McClelland (1986) [14] proposed a technique that suggests how an attentional selective mechanism might work. They propose the use of a set of mapping units which produce "dynamically programmable connections" and achieve focusing on different features on different times. Smolensky (1986) maintains that schemata are coherent assemblies of knowledge atoms. where coherence or consistency is formalized under the name of harmony. He proposes the harmony principle: the cognitive system is activating coherent assemblies of atoms, and draws inferences that are consistent with the knowledge represented by the activated atoms.

In much the same way, we propose to speak about "motoric schemas". This is consistent with our conjecture that there is no essential difference between the so-called "cognitive" and "motoric" brain mechanism. The connectionist schema-model is also consistent with the neural evidence. that

the specialization among different cortical motor areas are related to certain sequences of movements, and not to transformations as proposed by the "motor program" literature. According to our conjecture, preparatory units and movement executing units will belong to the same schema. This is supported by the anatomical fact that the three motor areas (SMA - Supplementary Motor Area, PMC - Primary Motor Cortex and Putamen), has the same proportion of target dependent motor cells and limb dependent movement-related cells ([2]). Another supporting evidence is that neuronal population that were supposed to represent different stages of computation (according to the "motor program" view), have been shown to be active simultaneously.

3   The experiment

3.1   Data collection

Rumelhart [13] developed a system which learns to recognize cursive script as it is generated by a writer. This system learns from examples of cursive script produced by a number of writers and recorded. He collected approximately 1000 words from each of 58 writers. The average length of a word is about 8 characters, That sums up to nearly 500,000 examples of handwritten cursive characters. His results were encouraging and had been used in this research. While Rumelhart [13] was mainly interested in handwriting recognition, this article uses the same data to investigate the writing mechanism.

The data were collected in the following manner. Each word in the corpus was recorded. It was then played to the writer who was instructed to write the word on a tablet digitizer. The resulting x coordinate, y coordinate and an indication of whether the pen was or was not on the paper were sampled each 10 milliseconds. The resolution (more than 200 dpi) and the sampling rate (100 samples/sec) are those that are shown to be appropriate in the on-line hand-writing recognition literature ([16]). The data was saved as files, and has been used for the analysis reported in this article.

In addition to the data from Rumelhart's experiment, several thousands pen strokes of Japanese handwriting were collected. Most of the data has been collected from hand written Hiragana characters, but some data has been collected during writing Kanji (idiographic) Japanese characters. Hiragana characters has the curved shapes of english hand printed characters,

but without the ligature of cursive handwriting.

Preprocessing of the hand-writing raw data has been made. with the goal of extracting features that will be used to segment and characterize the "pen-strokes". A pen stroke was defined as a segments of the cursive writing signal. between two consecutive zero crossing of the vertical velocity of the pen movement. Each character was segmented to several segments or "pen-strokes". A typical writing rate in English is two letters per second. Writing Japanese characters (Hiragana). takes about the same time, and a typical Hiragana character can be written in 0.3 - 0.5 seconds.

3.2   Segmentation and feature extraction

The principle of segmentation and feature extraction is to segment the continuous signals into discrete segments and to represent each segment by a feature vector in the feature space.

The segmentation that produces "pen-strokes" out of the continuous signals, depends on the different definitions of the term"pen-strokes". While most of the literature about on-line character recognition is using this term, there isn't an agreed upon definition of a "pen-stroke". For example, one often finds only the pen-state change as the only criteria. That is. definition of a stroke as continuous pen-movement. between pen-down and pen-up consecutive states [16].

Once a "pen-stroke" is defined. there are many ways to represent it in a feature space. The on-line character recognition research employs several orthogonal transformations such as a discrete Fourier transform of the curve segments corresponding to the pen-strokes. That is. a pen-stroke is represented by its Fourier coefficients obtained from its $x(t)$ and $y(t)$ signals. Essentially, any orthogonal transformation (e.g. Walsh transform, Karhunen-Loeve) could do in approximating the pen-strokes curves. That is, Plane curves can be approximated by orthogonal functions (Sinusoidal, polynomial or even square waves). This description can be also easily converted to the frequency domain. as was done in several studies of hand-writing recognition [16].

This mapping of the time domain to a parametric domain is advantageous when the characters can be represented by a small number of coefficients. Therefore. periodical smooth curves lend themselves better to modeling by harmonic functions. as one needs less coefficients. On the other

hand. straight line strokes require high order harmonies as they include high frequency components. This is why sinusoidal approximation is useful for characters consisting of curved strokes, as found in English cursive script, more than for Japanese Kanji characters (that are made mainly of straight line segments). K-L expansion has been proved to be a successful algorithm in machine-printed Chinese character recognition. Another successful attempt was to use a modified Hough transform for recognition of Chinese hand-written characters. The Hough transform is a technique for line detection and has been generalized to detect arbitrary shapes. Chinese characters are line-like, and therefor lend themselves naturally to a Hough transform representation.

The segmentation and feature extraction methods depend of course, on the goal. If the goal is pattern recognition, then the segmentation and feature extraction are geared toward discrimination between the various patterns. In our case, we looked for a segmentation and features that are biological plausible. Consequently, we investigated only features that might be explained by the neurobiological control structures, like the direction of the strokes, their curvature etc.

3.3   Hollerbach's model

The segmentation and feature extraction mechanism employed was. to develop a model of the underlying handwriting process and to describe the data in terms of the parameters of the model. The model employed was derived from that of Hollerbach [10] and involved the assumption that the generation process could be described as pair of coupled oscillators. The coupled harmonic oscillators is just one of the many models that exist. Actually, its basic assumption about the symmetric shape of the velocity profile (an half sinus shape), is probably an oversimplification. The literature about velocity profiles of pen-strokes usually assumes an asymetrical bell-shaped velocity profile. That is, a rapid-aimed movement described by a log-normal velocity profile is considered as the fundamental unit (stroke). More complex movements are described in terms of superimposed log-normal curves. The asymmetric nature of the velocity bell-shaped profile results from the global stochastic behavior of a large number of processes involved in velocity control.

In spite of being an oversimplified and inaccurate model, it has a clear

advantage that it is based on a control mechanism, and is neurobiologically interpretable. This model assumed that:

$$\dot{x} = a\cos(\omega_x t + \phi) + c \qquad (1)$$
$$\dot{y} = b\cos(\omega_y t) \qquad (2)$$

In words, the idea is simply that writing involves two orthogonal pendular movements. If we speak about writing in a notebook (small size letters), we can think about the wrist horizontal movements (actually, it is more arc-like movements) and the fingers flexion andextension vertical movement. These two movements can be considered as independent. If the size of the letters is more than an inch, than the arm muscles are involved.

According to this model, The y-axis consists of a series of up/down strokes whose velocity profile is assumed to be sinusoidal. The x-axis is also pendular with a constant velocity, c, to the right. Different characters are made by modulating the relative amplitudes, a and b, the relative phase, phi, and the relative frequency ω_x and ω_y, in the x and y directions. It is, furthermore assumed that the parameters change only when the velocity in the y direction reaches zero (end of pen-stroke). Thus, we define a *stroke* as the motion between zero crossings in the y velocity - v_y. In addition, segmentation occurs when the pen-state changes (from pen-down to pen-up or vice versa).

It should be stressed that Hollerbach's model was designed for synthesizing handwritten-like character, by a second order mechanical system. This model does not try to imitate the human motor control, or to be used for analysis of human handwriting. However, as it is a control system model, some of the parameters might be interpreted in terms of the human biomechanical system. For example, the parameter ϕ, which designates the phase shift, can be interpreted as relating to the delay in the nervous-muscular control system. As such, it can have an important diagnostic value in motor diseases.

When it was applied by Rumelhart to handwriting analysis, it suffered from some drawbacks. One of them is that the model is fitted not to the image, but to the **velocity** profile of the stroke. This simplifications tend to work well in most of the cases of English cursive hand-writing, because of the periodical nature of the v_y velocity signal.

As the Hollerbach model that we used, is based mainly on the velocity signals, we will illustrate the transformation from the $x - y$ domain of the hand-
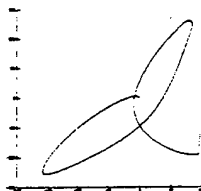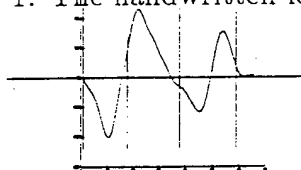
Figure 1: The handwritten letter d

Figure 2: The v_x graph for the handwritten letter d

written character, to the corresponding velocities. Examples of the handwritten letter d, the corresponding velocity profiles and the reconstructed d are shown in Figures 1,2,3 and 4.

As can be seen, the reconstruction isn't perfect, and the curvature of the first pen-stroke of the d is opposite to the original. This result illustrates the fact that the model tries to reconstruct the velocities and not the resulting pen strokes image.

This does not exclude the fact that sinusoidal approximation worked for Rumelhart in recognition of cursive script. It turned out that in some cases (periodic signals during cursive handwriting in English) the model worked satisfactorily.

The Kanji characters, on the other hand, have more short straight segments, as can be seen in the following figures:

The "mori" Kanji character in the picture, is segmented to 27 pen-strokes (the last two pen-down strokes in the third "tree" are missing). Sixteen out of the twenty seven, are strokes in which the pen touched the paper, and 11 were just for moving the pen from one line to the other. Twelve sequences of "pen-down" strokes, correspond to the visible line segments in the character.
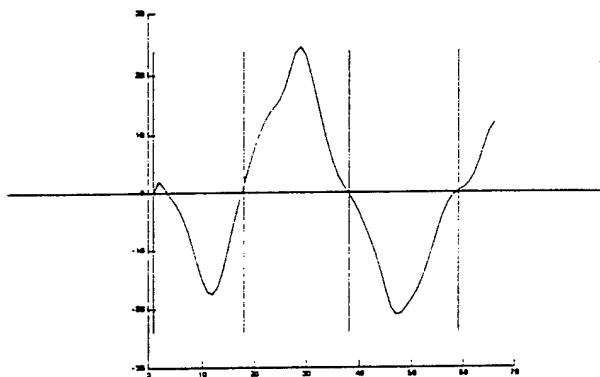
Figure 3: The v_y graph for the handwritten letter d
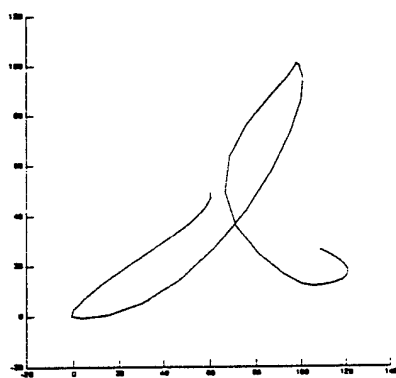
Figure 4: The reconstructed letter d
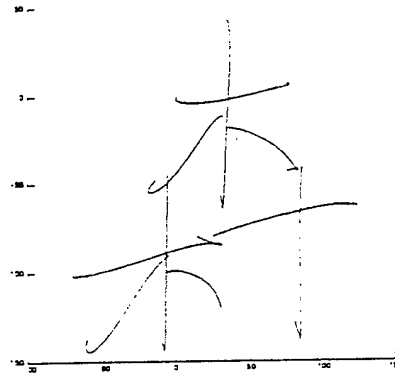
Figure 5: The separate strokes are more evident in Japanese Kanji characters. This is the Kanji character: "mori", which means: forest

y	x	Mid	Velocity	Harmony	Pen up-down
0.70	7.41	0.74	-2.95	4	1
3.44	-3.86	-2.77	-2.20	4	0
-10.56	-0.45	-0.01		2	1
0.71	-0.13	0.04	-0.33	2	1
4.40	0.08	-0.59	2.62	2	0
-4.20	-4.94	-1.88	-3.19	2	1
3.87	4.61	1.55	5.46	2	0
-2.67	5.51	3.63	-2.33	2	1
-5.74	-15.08	-7.31	-4.36	2	0
1.64	9.70	2.62	8.60	2	1
0.42	-1.46	0.23	-4.40	2	1
3.27	-1.99	-1.85	0.75	2	0
-9.71	-0.19	-0.04	-0.20	2	1
5.45	0.47	-1.20	3.70	4	0
-5.40	-5.85	-3.39	-2.74	4	1
4.29	4.89	0.84	10.50	2	0
-1.91	4.29	3.38	-1.56	2	1
3.91	-0.64	1.55	-3.30	4	0
1.82	9.72	3.70	6.74	2	1
0.07	-1.35	0.46	-5.25	2	1
2.00	-2.17	-2.12	1.86	2	0
-9.60	-0.18	-0.18	-0.28	4	1
0.98	-0.37	-0.09	-0.74	2	1
4.52	0.57	-0.33	-0.12	4	0
-4.22	-5.45	-2.72	-2.64	4	1
4.14	6.24	4.40	5.90	4	0
-5.10	7.23	4.61	0.54	4	1
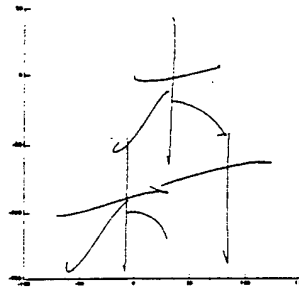
Figure 6: v_y signal for the Kanji character: "mori".
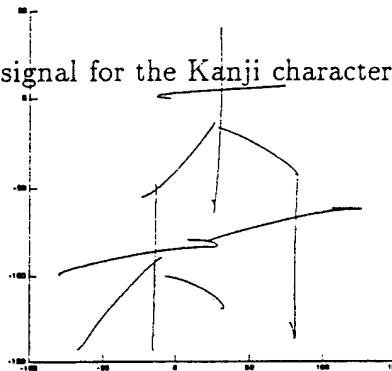
Figure 7: The reconstructed Kanji character: "mori".

The reconstructed Kanji character is depicted in the figure.

3.4   Recognizing pen-strokes sequences

One of the key problems in recognizing cursive handwriting is the segmentation problem. Rumelhart [13] has devised a learning algorithm for cursive handwriting recognition which combines word recognition and letter recognition. The letter recognition is based on recognizing PMPs, and PMPs sequences make letters. This system involves simultaneously learning to recognize and segment letters.

Although Rumelhart's experiment was done for hand-writing recognition, there are several things that can be learned from it, concerning the PMPs and their sequencing during handwriting. It was recognized in the early sixties

([6]). that motor knowledge can be used in recognition of hand-writing. A system called *Analysis by synthesis* suggests that characters are recognized by their "motor programs". These "motor programs" are supposedly deduced by guessing an initial program, and iteratively updating it according to the difference between the synthesized and actual forms. The connection between reading and writing process have been corroborated by the co-occurrence of certain kinds of acquired dysgraphia and dyslexia ([5]). In contrast to earlier approaches. Edelman et al., ([6]). assumes that while readers use motor knowledge in reading, they do not seem to do so by mentally reproducing the process of writing. The connectionist model that we propose isn't bothered. of course. by those distinctions between explicit simulation or implicit knowledge. This is another example of the misleading influence created by the "motor programs" metaphor.

4   The results of clustering

4.1   fixed radius clustering

The basic units of clustering were the pen-strokes. each of which was represented as a point in an n dimensional space. Out of the six features that we extracted for each stroke only three have been used. First, we used only one frequency for the modeling, so the rare strokes that involved higher harmonies were removed. Second, we did not differentiated between Up-strokes and Down-strokes. Up strokes contain more high order harmonies. but we limited our analysis to the basic movements, and tried to ignore the fluctuation induced by the bio-mechanical control mechanism. The third feature that wasn't used was the mid-point. For the reconstruction of the pen-strokes in the spatial domain, the x-coordinate of the midpoint in each stroke was computed. However. our preliminary analysis showed that this variable was very highly correlated with the x variable. This preliminary analysis. yielded three variables that were almost uncorrelated: Δ_x, Δ_Y and velocity. The dimension of the space were:

1. Δ_y - The relative displacement on the vertical direction.

2. Δ_x - The relative displacement on the horizontal direction.

3. v - v The v_z velocity at the end of the stroke is calculated according to equation below.

For a pen-stroke between a and b, which is approximated by a certain oscillation frequency, we calculate:

$$I_x = \int_a^b dx \cos(2\omega_x t) \tag{3}$$

$$v = [\frac{x_a - x_b}{l}] - [\frac{2I_x}{l}] \tag{4}$$

$$\tag{5}$$

It is calculated in a different way for different ωt and this is an example of such a calculation.

The clustering of data from many writers, didn't yield satisfactorily clustering, but the clustering of individual writers did. E.g. the clustering for a particular writer, revealed 13 compact clusters that contained 90to 14. were consistent to all the writers we analyzed. This is a corroboration to our conjecture that hand writing is made out of a small number of PMPs, which are unique to an individual writer.

The centroids of the clusters, were reconstructed from the feature space, and are displayed on a 2-D spatial domain. As can be seen clearly from the results, different writers have different stroke types:

As each writer has about 25.000 pen-strokes that we wanted to cluster, we started with a fast clustering algorithm, similar to the k-means algorithm. The main requirement of the clustering algorithm were that it will be able to deal with very large data sets and find satisfactory clusters in few (2-3) iterations. The other requirement, which was even more important, was that the centroids will be good representations of the observations within each cluster. This requirement lead to seeking compact, hyperspherical clusters, that do not exceed a predefined radius. Elongate clusters are therefore represented by several adjacent clusters. Those clusters will be merged in a latter stage by an hierarchical clustering algorithm.

The clustering employed a two phase strategy. First, a fast "nearest centroid sorting" algorithm was employed to reveal the clusters in the large data set. Then, the resulting centroids of the clusters have been submitted to different hierarchical clustering methods. The first phase algorithm was
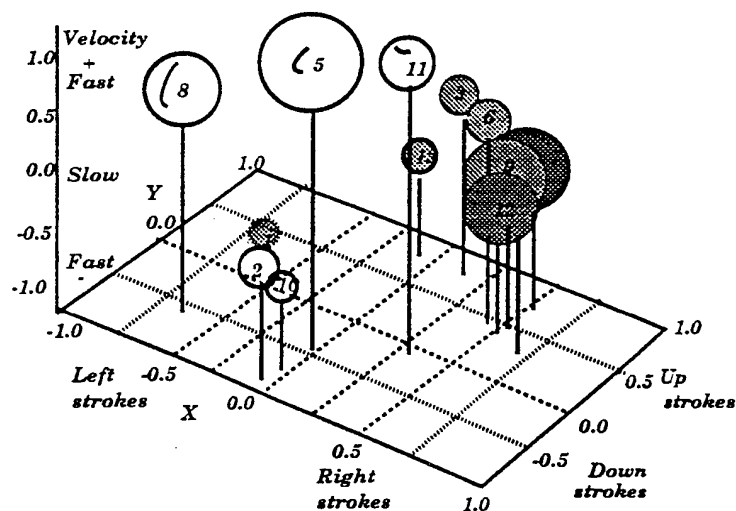
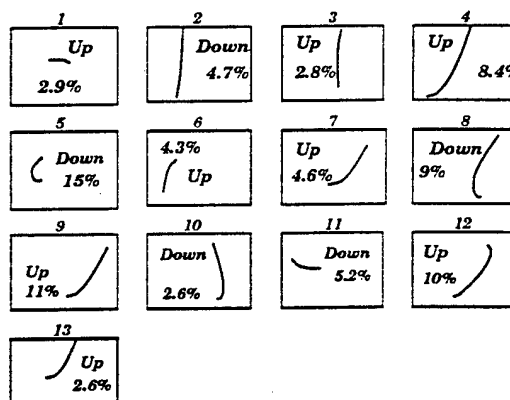Figure 8: Clustering of 25,000 strokes of the same writer. Gray clusters represent down strokes.

Figure 9: Thirteen centroid pen-strokes of an individual writer, including their relative frequencies.

sensitive to outlier strokes. that formed separate clusters. This was the reason
why we got many very small clusters. These clusters accounted for less than
10of the observations. They were considered to be noise, or very exeptional
pen strokes, and have been removed so not to influence the representativeness
of the centroids of the large clusters.

The second phase included clustering of the resulting centroids using ten
different methods. We distinguished between methods that yield compact
hyperspherical clusters, and those that can detect elongate clusters. We
start with the first group of eight clustering methods:

1. Average Linkage cluster analysis

2. Centroid hierarchical cluster analysis

3. complete linkage cluster analysis

4. Equal variance maximum likelihood method

5. Flexible data cluster analysis

6. McQuitty's similarity analysis

7. Median Hierarchical cluster analysis

8. Ward's minimum variance cluster analysis

The different methods tend to favor different characteristics such as size,
shape or dispersion. For example. methods based on the least-squares cri-
terion such as k-means or Ward's minimum variance method, tend to find
clusters with roughly the same number of observations in each cluster. Aver-
age linkage is biased toward finding clusters of equal variance. Most cluster-
ing algorithms, except for single-linkage and density-linkage, tend to produce
compact, roughly hyperspherical clusters. The clustering methods which are
based on nonparametric density estimation, like the single linkage. will be
discussed later in this chapter.

All the above clustering methods yielded very similar results. and the
tree-based partition was essentially the same. The use of many different
algorithms has been employed to investigate the robustness of the clustering
structure under different hierarchical clustering methods. The result of all
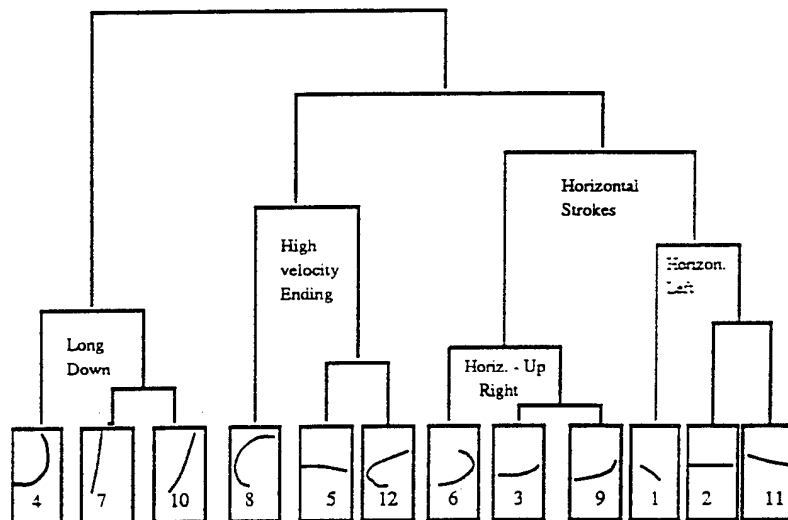
Figure 10: Hierarchical (compact) clustering of the 12 pen-strokes centroids
of a particular writer

the above method revealed the following tree-based partition of the set of
the basic twelve pen-strokes (of a particular writer).

From looking at the results of the hierarchical clustering, there is an obvious super-clusters that emerge. The horizontal-left strokes are one such a group, long down strokes are another group. In general we see a distinction between horizontal strokes and vertical strokes. The horizontal strokes themselves are subdivided to horizontal-left directed strokes, and horizontal right and up directed strokes. The high velocity C shaped strokes are part of circles or ovals. It should be noticed that for a specific writer, a certain stroke is always accomplished in the same way. For example, an horizontal short stroke, like crossing a t, will be done always as left directed strokes. Someone else could use only horizontal right directed strokes for that purpose. However, it is very unlikely that the same writer will use both an horizontal-left and horizontal-right strokes. The same is true with long vertical strokes. Once the writer is using a long vertical down-stroke. he will produce vertical lines always as down strokes of the same type and velocity profile. This organization of pen strokes was consistent in all the hierarchical
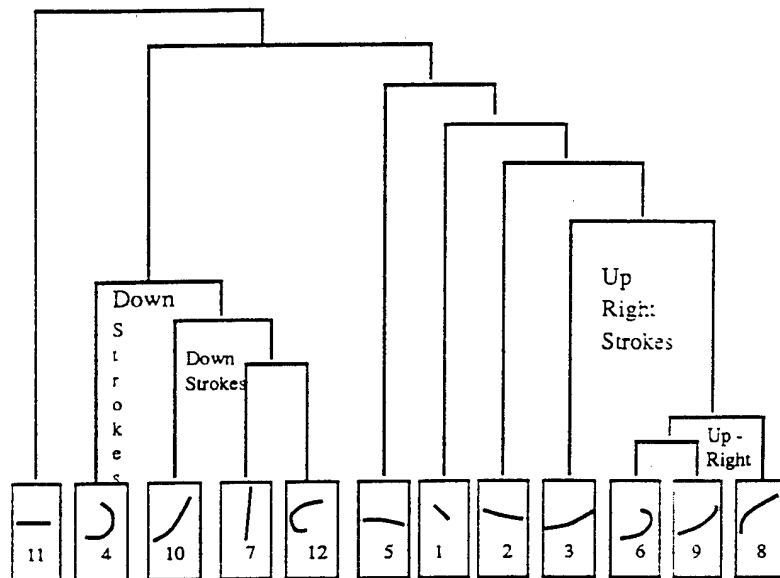
Figure 11: Hierarchical (Density linkage) clustering of the 12 pen-strokes of the same writer

clustering algorithms that we mentioned above.

The clustering methods that employ nonparametric density estimation, like the "Density linkage cluster analysis", can detect also elongated cluster shapes. These clustering techniques yielded two distinct super clusters: the "down and long pen-strokes" , and the "up and right strokes". The down strokes are those that form the "back-bone" of the English characters. while the up-right strokes are typically those that are used as ligature.

4.1.1 The "characteristic" shape of pen-strokes

As was argued above, any writer has a specific set of pen strokes that characterize the writer. While the same writer will have similar pen-strokes, in writing different languages, the frequency of appearance of a specific pen strokes depends. of course, on the language. In order to characterized a specific writer, in respect to her/his pen strokes. we suggest the "Pen-strokes Ordering Diagram" (POD). Such PODs are displayed in the following figures.

In spite of their strange looking. those diagrams are quite valuable. and convey important information about the handwriting of the analyzed writer.
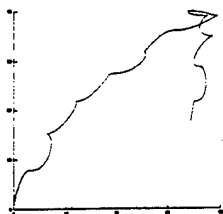
Figure 12: The centroids of the pen strokes of a writer, for English cursive writing. The pen-strokes are ordered according to their v_y values. from up-strokes to down strokes
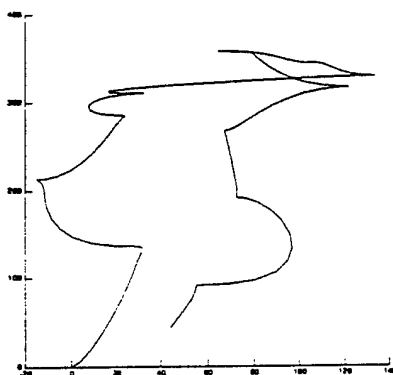
Figure 13: The centroids of the pen strokes of a Japanese writer, for Japanese Hiragana characters. The pen-strokes are ordered according to their v_y values. from up-strokes to down strokes
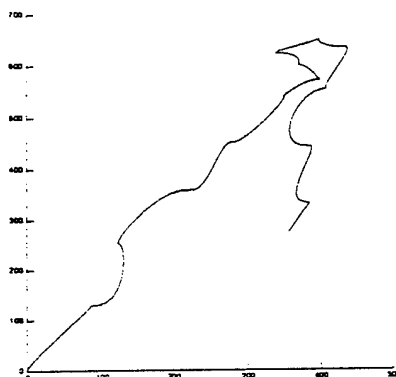
Figure 14: The centroids of the pen strokes of a Japanese writer, for english characters. The pen-strokes are ordered according to their v_y values, from up-strokes to down strokes

There is a very clear distinction between the key strokes that these two writers are using. This is true to other writers as well. Each writer uses a unique set of pen-strokes: different slopes, different curvetures. different velocity profiles and accelerations.

5   Discussion and future research

We will start our discussion with comparing the conclusions of Rumelhart's handwriting recognition experiment, and the conclusions of this study. In Rumelhart's handwriting recognition experiments, both writer dependent and writer independent recognizers have been trained. Two networks have been trained to recognize the writing of individual writers and one network has been trained on four different writers as a "writer independent" recognizer. On the writer dependent networks Rumelhart found that, for a vocabulary of 1000 words, on words never seen during training that 99top five, approximately 90On the writer independent data the results are somewhat worse. That is, about 70

According to the results in this study, we have a basis to doubt this conclusion. The inter-writer variability is too big, and more writers will not lead necessarily to better results.

Another finding of Rumelhart was that writers can be trained easily to

produce recognizable hand writing. He developed an "online" system in
which the network recognizes (and can be trained) as the writer writes on
the digitizer. With a little care on the part of the writer it is not difficult to
achieve a score of better than 90correctly classified on the writer independent
system. (It is also possible to write so that the recognizer does much more
poorly than that. Careful experiments on a person's ability to adjust to
the recognizer have not been carried out. By limiting the vocabulary to
one hundred words or less. it seems to be possible to obtain near perfect
performance. (It will. of course. depend on the confusability of the words.)

The main conclusion was. that it would be useful to embed the recognizer
in a network of networks each trained on a subset of the writers – perhaps one
for printers. one for pure cursive writers etc. This line of thought led to the
current study, reported in this article. That is, that it may be useful to study
the individual differences among the writers. The idea of studying individual
differences. as a mean towards better handwriting recognition, turned out to
start a new line of research - the study of writer's unique pen-strokes. which
is related to the topic of automaticity in brain - hand communication.

This study started from that point. The main question that we posed
was if individual writers have distinct sets of pen-strokes, which are con-
sistent and well defined. The reanalysis of the data from this perspective
encourage to believe that this is the case. Human writers have 12-14 distinct
pen-strokes, which are characteristic for a certain writer. These pen-strokes
are the primitive "motoric patterns". of which handwriting is composed. We
showed also that the primitive pen-strokes cluster to super-clusters. thus re-
vealing the hierarchical nature of the control mechamnism. These findings
are consistent with the neurological literature, that we cited in the introduc-
tion. That is, there might be "command cells", that get the activation for
certain words (letter combinations) from another center in the brain and acti-
vate pen-strokes mechanism. The pen-stroke is controlled by a direction and
amplitude cells, that activate the corresponding primitive motoric patterns
(PMPs). The next stage will be to locate the cell regions that are responsi-
ble for this activation in the motor areas of the human brain. This is under
research now with the help of Magnetic Resonance Imaging (MRI) method,
when the MRI is tuned to detect cerebral blood flow. We would expect that
the learning to write. should show itself as forming of such motoric activation
centers. corresponding to what we have found in this study.

Those findings have implications to the study of automaticity and chunk-

ing. One question to be investigated is if the motor control mechanism is central and a modal, as suggested by previous researchers. This can be investigated by studying the patterns of interference between modalities. For example, an experiment in which the subject is instructed to pronounce one character, and write another character at the same time. In addition to predicting longer Reaction Time, we can now predict interference between the pen stroke patterns and sequences. Another interesting question is how are the motoric patterns stored and how are they retrieved when needed. Our conjecture, which is consistent with the neural net model, is that the retrieval time will be independent of the number of patterns sequences. Some support for this conjecture is that it takes the same time to write a character in a large character set (kanji) or small character set language (Hiragana, English).

Future research that will combine behavioral analysis with neurobiological research, might answer many of the questions that we raised in the introduction.

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```
#include <conio.h>
#include <stdio.h>
#include <signal.h>
#include <math.h>
#include <stdlib.h>
#include <graphics.h>
#include <dos.h>
#include <string.h>
#include <values.h>
#include <iostream.h>
#include <alloc.h>
#include <time.h>
#include <ctype.h>
#include "q_lib.h"
#include "start.h"

#define DMAX 400
#define PERIOD_CONST  10

#define T 0.01
#define NUMBER_CHANNEL 5
#define del 20

pos_st POS_ST[DMAX];

FILE *point,*fp;

int pen_up=0;

int init_board (void);
extern unsigned _stklen=0x8000;
int read_acc (char *filename);
void ini_msg(void);
void next_point(void);
void read_smooth_point(int number);
void read_averag_point(float xyz[],long num);
void get_acc(void);

#ifdef __cplusplus
   typedef void (*fptr)(int);
#else
   typedef void (*fptr)();
#endif
unsigned int shift_cnt=0;
int Catcher(int *reglist)
{
  printf("Caught it!\n"); /* make return AX = 3 */
  return 0;
}
```

```
/* First filteration by Butterworth digital filter 4'th order and
    0.1 cutoff freq.
    Input : array of accel. POS_ST and index of point ind1.
    Output : smoothed values in array POS_ST */
void butter_filt4(pos_st POS_ST[],int ind1)
{
 static float a[5]={1.,-3.180639,3.861194,-2.112155,.438265};
 static float b[5]={.000416599,.001666397,.002499595,.001666397,.000416599};
 static float y[4][5],x[4][5];
 int i,j;
 float sum=0.;
 static int cnt=0;
 for(j=0;j<4;j++)
  {
    if ( cnt<5 )
      y[j][4-cnt] = POS_ST[ind1].AR[j];
    for(i=4;i>0;i--)
      x[j][i] = x[j][i-1];
    x[j][0] = POS_ST[ind1].AR[j];
    if ( cnt >= 5 )
     {
       sum = 0;
       for(i=4;i>0;i--)
         y[j][i] = y[j][i-1];
       for(i=0;i<5;i++)
         sum += b[i]*x[j][i];
       for(i=1;i<5;i++)
         sum -= a[i]*y[j][i];
       y[j][0] = sum;
       POS_ST[ind1].AR[j] = sum;
     }
  }
 if ( cnt < 5 ) cnt++;
}
```

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```
float DIF[2]={0,0},DIF0[2]={0,0};
/* Second filteration by Butterworth digital filter 4'th order and
   0.02 cutoff freq.
   Input : X and Y accel.
   Output : smoothed values in global variable DIF */
void butter_filt0(float dif[2],int fl)
{
       static               double
a[5]={1.e+00,-3.83582554064735e+00,5.52081913662223e+00,-3.53353521946302
e+00,8.48555999266478e-01};
       static               double
b[5]={8.98486146372335e-07,3.59394458504525e-06,5.39091688001037e-06,3.59
394458371298e-06,8.98486146816424e-07};
    static float y[2][5],x[2][5];
    int i,j;
    float sum=0.;
    static int cnt=0;
     if (cnt == 5 && fl)
        cnt=0;
     for(j=0;j<2;j++)
      {
       if ( cnt<5 )
         {
          for(i=0;i<5;i++)
            {
             y[j][i] = dif[j];
             x[j][i] = dif[j];
            }
         }
        for(i=4;i>0;i--)
          x[j][i] = x[j][i-1];
        x[j][0] = dif[j];
        if ( cnt >= 5 )
          {
            sum = 0;
            for(i=4;i>0;i--)
               y[j][i] = y[j][i-1];
            for(i=0;i<5;i++)
              sum += b[i]*x[j][i];
            for(i=1;i<5;i++)
              sum -= a[i]*y[j][i];
            y[j][0] = sum;
            DIF[j]= sum;
          }
      }
     if ( cnt < 5 ) cnt=5;
}
```

```
/* Function for compensation of second filter delay,
   make delay for outputs of first filter.
   Input:d1 and d2 current difference of signals in a pair
   Output: delayed difference signal */
void set_delay(float d1,float d2,float &res1,float &res2)
{static h_cnt=0,t_cnt=0;
 static float diff_acc[2][50];
 diff_acc[0][t_cnt]=d1;
 diff_acc[1][t_cnt]=d2;
 if ( (h_cnt-t_cnt+del)%del == del-1 )
    {
      res1 = diff_acc[0][h_cnt];
      res2 = diff_acc[1][h_cnt];
      h_cnt = (h_cnt+1) % del;
    }
 t_cnt = (t_cnt+1) % del;
}


struct send_data
    {int period; //T
     float ampl; //A
     float incr_acc; //V
     };
send_data params[2][DMAX];
/*      This procedure gets as inputs two signals (after the filteration) for each
        accelerometer and the pen status.  The procedure performs segmentation of
        the signals and calculation of each segment's features  */
void get_pack_param(send_data params[2][DMAX])
{static int fl_opt=0,cnt_seg[2]={0,0};
 static int cnt_t[2];
 static float p_dacc[2]={0,0},beg_dacc[2]={0,0};
 static float max_ampl[2]={0,0},beg_xyacc[2]={0,0};
 int i;
 float dacc[2];
 set_delay(POS_ST[1].AR[0]-PEN.R[0]-POS_ST[1].AR[1] + PEN.R[1],
        POS_ST[1].AR[2]-PEN.R[2]-POS_ST[1].AR[3] + PEN.R[3],
        dacc[0],dacc[1]);
  if (!pen_up)
   {
   for (i=0;i<2;i++)
    {
    if ( fl_opt )
      {
        if ( dacc[i]*p_dacc[i] <= 0. )
          {
            params[i][cnt_seg[i]].period=cnt_t[i];
            params[i][cnt_seg[i]].ampl=max_ampl[i];
            params[i][cnt_seg[i]].incr_acc=DIF[i]-beg_xyacc[i];
            cnt_seg[i]++;
```

```
              params[i][cnt_seg[i]].period= -1;
              p_dacc[i]=dacc[i];
              beg_dacc[i]=dacc[i];
              beg_xyacc[i]=DIF[i];
              max_ampl[i]=0;
              cnt_t[i]=0;
            }
          else
            {
              p_dacc[i]=dacc[i];
              if (fabs(max_ampl[i])<fabs(dacc[i]))
                   max_ampl[i] = dacc[i];
              cnt_t[i]++;
            }
        }

     if (!fl_opt && (fabs(dacc[0])>5. || fabs(dacc[1])>5.))
        {
          fl_opt = 1;
          cnt_t[0]= cnt_t[1] = 0;
          memcpy(p_dacc,dacc,sizeof(float)*2);
          memcpy(beg_dacc,dacc,sizeof(float)*2);
          memcpy(beg_xyacc,DIF,sizeof(float)*2);
        }
      }
     }
    else
     {
        params[0][++cnt_seg[0]].period= -1;
        params[1][++cnt_seg[1]].period= -1;
     }
  }
```

APPENDIX C

The microcontroller gets as inputs the signals of the accelerometers, performs segmentation of it in time (listing of the segmentation program is in appendix B) and represent each segment by several parameters which are transmitted to the receiver.

The segmentation of each signal is performed by the movement of the center of oscillations and amplitude and frequency of the oscillations. The procedure of segmentation and feature's extraction consists of the next steps:

- Dividing of the original signal into two components: the signal of the movement of the center of oscillations and the signal of oscillations. The first signal is obtained by filtering the acceleration signal from an accelerometer using Butterworth digital filter as described in Digital Filter Design, T.W.Parks and C.S. Burrus, John Wiley & Sons, 1987, chapter 7, section 7.3.3, with 4'th order and 0.02 cutoff frequency. The second signal is obtained by filtering of the differential signal of two accelerometers in a pair, using the Butterworth filter with 4'th order and 0.1 cutoff frequency.

- Segmentation of the signal according to the zeros of the oscillations signal.

- Features extraction - The features that we are using to define each segment are:

    - Duration between the edges of the segment (T).
    - Amplitude of oscillations (A).
    - The difference between the values of first signal at the edges of segment (V)

<u>Fax Pen</u>

<u>Generator of strokes for hand imaging</u>

```
#include <stdio.h>
#include <alloc.h>
#include <math.h>
#include <string.h>
#include <graphics.h>
#include <process.h>
#include "st.h"
int far arr_x1[15000],arr_y1[15000];
void send_p ( unsigned , char * , unsigned   );//sending from
com-port
int init_com ( int   , unsigned );
   void segment(int num_p,unsigned int far p_x[],unsigned int far
p_y[],char *p)
{
extern float xmax,ymax;
extern shiftx;
extern char *arg_str[];
    int  v_x[2][1000];
    int  v_y[2][1000];
    int  extrxy[2][1000];
    int attr=0;
// structure of binary file of data from graphic tablet
    struct point
      {
       unsigned x :13;
       unsigned y :13;
       int pen :6;
      } pnt;
// structure of binary file of coefficients of the cubic spline
    struct stroke
      {
       unsigned x :13;
       unsigned y :13;
       signed alf1:11;
       signed alf2:11;
      } strk;
    char buff[20];
     int j;
    int newp;
    int num_points;
    int m;
    float lastx,lasty;
    int lvx,lvy;
    FILE *fp1;
    int count,i;
    unsigned long size_file = 0 ;
    int f1;
    int lpoint,fpoint;
    unsigned  base;
    char *p1;
    char *exten={".str"};
    int ascii=0;
```

```
/* test for extension ".str".If true - it is the ASCII format *
 * for creating a stokes file                                 */
    strlwr(arg_str[2]);
    if ((strstr(arg_str[2],exten))!=NULL) ascii=1;


    p1=p;
    newp=num_p;
 for(j=0;j<15000;j++){
 arr_x1[j]=0;arr_y1[j]=0;
 }
 /*---------------------------------------*/
/*                                            *
 *  writing binary file with data from graphic tablet   *
 *                                            */
   if ((fp1 = fopen (arg_str[1] ,"wb"))!=NULL)
   {
     for (count=0;count<num_p ;count++)

     {
     int p;
    if (p_x[count]<shiftx)
     {
     pnt.x=(unsigned)p_x[count];
     p=1;
     }
     else
     {
     pnt.x=(unsigned)(p_x[count]-shiftx);
     p=0;
     }
    pnt.y=(unsigned)p_y[count];
    pnt.pen=p;
    fwrite (&pnt,sizeof(pnt),1,fp1);
     }
     fseek ( fp1 , 0L , SEEK_END ) ;
     size_file = ftell ( fp1 ) ;
     sprintf (buff,"%lu",size_file ) ;
     setcolor(13);
     settextstyle(0,0,1);
     outtextxy(168,40,buff);

     fclose(fp1) ;
   }
   /*---------------------------------------*/
   lpoint=fpoint=0;
   fl=1;
   while (num_p>lpoint)
 {
   for (i=fpoint;p_x[i]>=shiftx && i<num_p;i++);
   attr=(unsigned)(p_x[i-1]-shiftx);
   for (j=i;p_x[j]<shiftx && j<num_p;j++)
    {
    arr_x1[j-i]=(float)p_x[j];
    arr_y1[j-i]=(float)p_y[j];
    }
   num_points=j-i;
   newp=num_points;
   fpoint=lpoint=j;
```

```
      /*********************/
       if (j<num_p)
        {

/*                                            *
  *              process segmentation          *
  *                                            */

       lastx=arr_x1[num_points-1];
       lasty=arr_y1[num_points-1];
       extrxy[0][0]=arr_x1[0];
       extrxy[1][0]=arr_y1[0];

    j=0;
    for(i=0;i<=newp-1;i++)
    { arr_y1[j]=arr_y1[i];
     arr_x1[j]=arr_x1[i];
       if (arr_y1[i]!=arr_y1[i+1])
        //&& arr_x1[i]!=arr_x1[i+1])
          j++;
          else
          num_points--;
     }
    newp=num_points;
/*-----------------------------------*/
       lvx=arr_x1[num_points-1]-arr_x1[num_points-2];
       lvy=arr_y1[num_points-1]-arr_y1[num_points-2];
       v_x[0][0]=(arr_x1[1]-arr_x1[0]);
       v_y[0][0]=(arr_y1[1]-arr_y1[0]);
       j=0;m=0;
/*-----------------------------------*/
    j=0;
    for(i=0;i<newp-1;i++)
    { arr_y1[j]=arr_y1[i];
     arr_x1[j]=arr_x1[i];
       if (arr_y1[i]!=arr_y1[i+1]
        && arr_x1[i]!=arr_x1[i+1])
          j++;
          else
          num_points--;
     }
    j=0;
    newp=num_points;
    for(i=0;i<newp-1;i++)
    {arr_y1[j]=arr_y1[i];
     arr_x1[j]=arr_x1[i];
       if (arr_y1[i]!=arr_y1[i+1]
        && arr_x1[i]!=arr_x1[i+1])
          j++;
          else
          num_points--;
     }
    j=0;
    newp=num_points;
    for(i=0;i<newp-1;i++)
    { arr_y1[j]=arr_y1[i];
     arr_x1[j]=arr_x1[i];
       if (arr_y1[i]!=arr_y1[i+1]
```

```
        && arr_x1[i]!=arr_x1[i+1])
          j++;
          else
          num_points--;
  }
/**************************/



/**************************/
  newp=num_points;
    j=1;
    m=0;
    setcolor(13);
    setfillstyle(1,9);

fillellipse((float)extrxy[0][0]*639/xmax,479-(float)extrxy[1][
0]*400/ymax-28,1,1);


  for(i=0;i<num_points-2;i++)
  {
  if (arr_y1[i]<arr_y1[i+1] && arr_y1[i+1]>arr_y1[i+2])
          {
          extrxy[0][j]=arr_x1[i+1];
          extrxy[1][j]=arr_y1[i+1];

fillellipse((float)extrxy[0][j]*639/xmax,479-(float)extrxy[1][
j]*400/ymax-28,1,1);
          v_x[0][j]=(arr_x1[i+2]-arr_x1[i+1]);
          v_y[0][j]=(arr_y1[i+2]-arr_y1[i+1]);
          v_x[1][j]=(arr_x1[i+1]-arr_x1[i]);
          v_y[1][j]=(arr_y1[i+1]-arr_y1[i]);
          j++;
          }
          else
   if (arr_y1[i]>arr_y1[i+1] && arr_y1[i+1]<arr_y1[i+2])
          {
          extrxy[0][j]=arr_x1[i+1];
          extrxy[1][j]=arr_y1[i+1];

fillellipse((float)extrxy[0][j]*639/xmax,479-(float)extrxy[1][
j]*400/ymax-28,1,1);
          v_x[0][j]=(arr_x1[i+2]-arr_x1[i+1]);
          v_y[0][j]=(arr_y1[i+2]-arr_y1[i+1]);
          v_x[1][j]=(arr_x1[i+1]-arr_x1[i]);
          v_y[1][j]=(arr_y1[i+1]-arr_y1[i]);
          j++;
          }
          else
   if (arr_x1[i]<arr_x1[i+1] && arr_x1[i+1]>arr_x1[i+2])
          {
          extrxy[0][j]=arr_x1[i+1];
          extrxy[1][j]=arr_y1[i+1];

fillellipse((float)extrxy[0][j]*639/xmax,479-(float)extrxy[1][
j]*400/ymax-28,1,1);
          v_x[0][j]=(arr_x1[i+2]-arr_x1[i+1]);
```

```
                  v_y[0][j]=(arr_y1[i+2]-arr_y1[i+1]);
                  v_x[1][j]=(arr_x1[i+1]-arr_x1[i]);
                  v_y[1][j]=(arr_y1[i+1]-arr_y1[i]);
                  j++;
                  }
                  else
        if (arr_x1[i]>arr_x1[i+1] && arr_x1[i+1]<arr_x1[i+2])
                  {
                  extrxy[0][j]=arr_x1[i+1];
                  extrxy[1][j]=arr_y1[i+1];

fillellipse((float)extrxy[0][j]*639/xmax,479-(float)extrxy[1][
j]*400/ymax-28,1,1);
                  v_x[0][j]=(arr_x1[i+2]-arr_x1[i+1]);
                  v_y[0][j]=(arr_y1[i+2]-arr_y1[i+1]);
                  v_x[1][j]=(arr_x1[i+1]-arr_x1[i]);
                  v_y[1][j]=(arr_y1[i+1]-arr_y1[i]);
                  j++;
                  }

        }
                  extrxy[0][j]=lastx;
                  extrxy[1][j]=lasty;

fillellipse((float)extrxy[0][j]*639/xmax,479-(float)extrxy[1][
j]*400/ymax-28,1,1);
                  v_x[1][j]=lvx;
                  v_y[1][j]=lvy;
                  j++;
/*-------------------------------------*/
                                                                  *
/*
* Calculating & writing a stroke file in binary or ASCII format*
 *
   */
 {  FILE *ff;
   if (fl)
   {
. ff =ascii ? fopen (arg_str[2],"w"):fopen (arg_str[2],"wb");
   if (ascii)
                              f     p    r    i    n    t    f
(ff,"(((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((
(((((((((((((((((((((\n");
   fl=0;
   }
      else
   ff =ascii ? fopen (arg_str[2],"a"):fopen (arg_str[2],"ab");
   if (j==2    &&    extrxy[0][0]==extrxy[0][1]    &&
extrxy[1][0]==extrxy[1][1])
   {int temp;
   j--;
   temp=j+(attr<<9);
   memcpy(p,&temp,2);
   p+=2;
   if (ascii)
   fprintf (ff,"%6d\n",temp);
      else
   fwrite(&temp,sizeof(j),1,ff);
     strk.x=(unsigned)extrxy[0][0];
```

```
strk.y=(unsigned)extrxy[1][0];
strk.alf1=0;
strk.alf2=0;
memcpy(p,&strk,sizeof(strk));
p+=sizeof(strk);
if (ascii)
f p r i n t f      ( f f ,  " % 4 d      % 4 d      % 6 d
%6d\n",extrxy[0][0],extrxy[1][0],0,0);
    else
fwrite (&strk,sizeof(strk),1,ff);
}
    else
{int temp;
temp=j+(attr<<9);
memcpy(p,&temp,2);
p+=2;
if (ascii)
fprintf (ff,"%6d\n",temp);
    else
fwrite(&temp,sizeof(j),1,ff);
for (m=0;m<j-1;m++)
{float vx,vy,vx1,vy1,al,al1,al2,mods,modv,dlx,dly;
dlx=extrxy[0][m]-extrxy[0][m+1];
dly=extrxy[1][m]-extrxy[1][m+1];
vx=v_x[0][m];
vy=v_y[0][m];
mods=sqrt(dlx*dlx+dly*dly);
if(mods==0.0) mods=1;

modv=(float)sqrt((vx*vx+vy*vy));
if(modv==0.0) modv=1;
al1=(dlx*vx+dly*vy);
if(al1==0.0) al1=0.01;
al2=(-dly*vx+dlx*vy);
al1=al2/al1;
/*-------*/
vx1=v_x[1][m+1];
vy1=v_y[1][m+1];
modv=(float)sqrt(vx1*vx1+vy1*vy1);
if(modv==0.0) modv=1;

al=(dlx*vx1+dly*vy1);
if(al==0.0) al=0.01;
al2=(-dly*vx1+dlx*vy1);
al=al2/al;
al2=al;
/*********/
if (m==j-2) al2=0.0;
if (m==0) al1=0.0;
if (sign(al2)*al2<0.35 && sign(al1)*al1>1) al1/=2.0;
if (sign(al1)*al1<0.35 && sign(al2)*al2>1) al2/=2.0;
if (sign(al1)*al1>5.0) al1=sign(al1)*1.0;
if (sign(al2)*al2>5.0) al2=sign(al2)*1.0;
strk.x=(unsigned)extrxy[0][m];
strk.y=(unsigned)extrxy[1][m];
strk.alf1=(signed)(al1*1023.0/5.0);
strk.alf2=(signed)(al2*1023.0/5.0);
memcpy(p,&strk,sizeof(strk));
```

```
      p+=sizeof(strk);
      if (ascii)
   fprintf (ff,"%4d %4d %6d %6d\n",extrxy[0][m],extrxy[1][m],
            strk.alf1,strk.alf2);
        else
   fwrite (&strk,sizeof(strk),1,ff);
    }
    strk.x=(unsigned)extrxy[0][m];
    strk.y=(unsigned)extrxy[1][m];
    strk.alf1=0;
    strk.alf2=0;
    memcpy(p,&strk,sizeof(strk));
    p+=sizeof(strk);
    if (ascii)
   fprintf (ff,"%4d %4d %6d %6d\n",extrxy[0][m],extrxy[1][m],
            strk.alf1,strk.alf2);
        else
   fwrite (&strk,sizeof(strk),1,ff);
   }
   fclose (ff);
  }
 }
 }

      if(!(base=init_com(2,9600))) exit(-1);
      send_p( base , p1 , (unsigned)(p-p1) );
      if (ascii)
     {int leng;
       char ch[20]={""};
   fp1 = fopen (arg_str[2],"a");
   fseek ( fp1 , 0L , SEEK_END ) ;
   f       p       r       i       n       t       f
(fp1,"))))))))))))))))))))))))))))))))))))))))))))))))))))))))
)))))))))))))))\n");
   fclose (fp1);
   strcpy(ch,arg_str[2]);
   leng=strlen(ch);
   strcpy(&ch[leng-3],"bst");
   fp1 = fopen (ch,"wb");
   fwrite(p1,(unsigned)(p-p1),1,fp1);
   fclose (fp1);
     }
 fp1 = fopen (arg_str[2],"r");
      fseek ( fp1 , 0L , SEEK_END ) ;
      size_file = ftell ( fp1 ) ;
      sprintf (buff,"%lu",size_file ) ;
      setcolor(13);
      if (ascii)
   {
   outtextxy(580,40,buff);
   sprintf (buff,"%lu",p-p1 ) ;
   outtextxy(368,40,buff);
   }
      else
   outtextxy(368,40,buff);
 fclose(fp1) ;
      free(p);
      free(p1);
 }
```

3.1. Definition of coordinate systems :
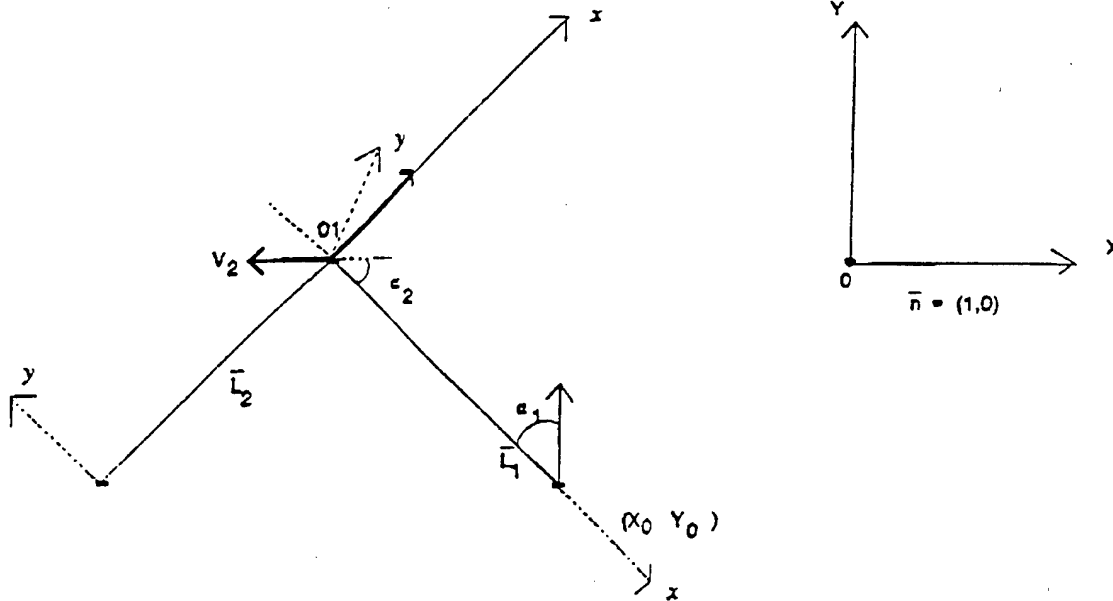
oyx-Intrinsic (Local) coordinate system describing the pen
stroke.

OYX-Extrinsic (Global) coordinate system describing the world
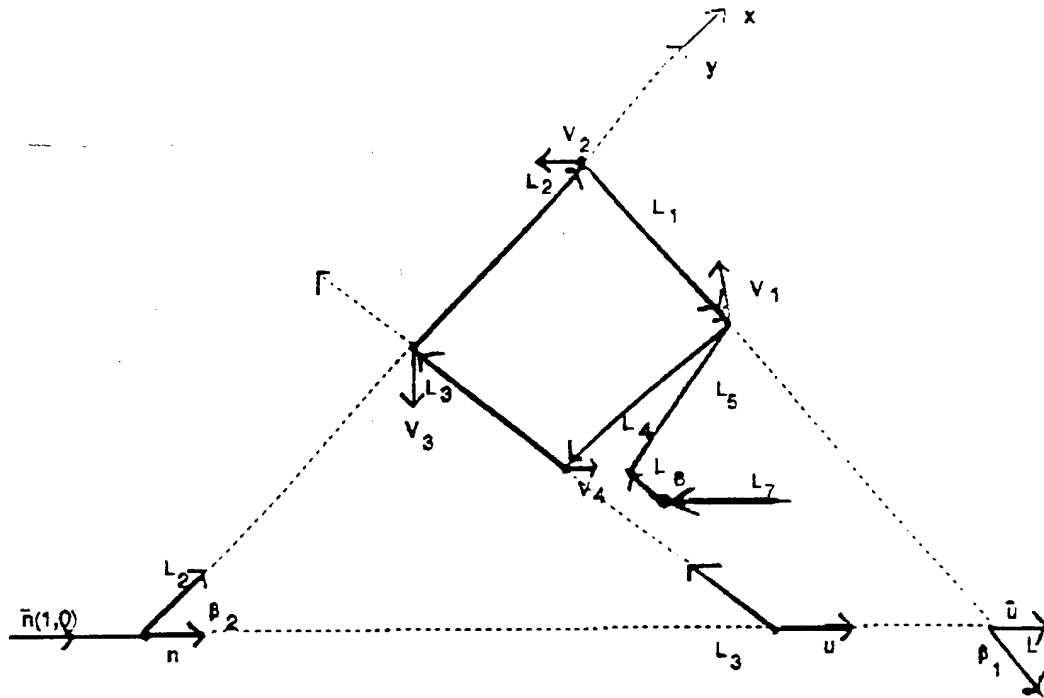(e.g computer screen)

<u>RECONSTRUCTION GOAL :</u>

generation of a sequence of third-order (cubic) splines in local

coordinate system and transition from the local oyx system to the

global OYX system.

The directions of the OYX vectors

$$\overline{L}_1, \overline{L}_2, \overline{L}_m$$

that define the segmentation of a symbol are chosen   in

accordance with the OX axes direction (local system).

In accordance with fig 2, the information needed for the

reconstruction of a symbol consist of :

$$\begin{pmatrix} \beta_1 \beta_2 \cdots \beta_m \\ \overline{L}_1 \overline{L}_2 \cdots \overline{L}_m \\ \overline{V}_1 \overline{V}_2 \cdots \overline{V}_m \end{pmatrix}$$

where

are the angles between the corresponding vectors .

$$\overline{L}1 \ldots \ldots \overline{L}_m$$

and the vector $\overline{n}$.

The vectors

$$\overline{V}1 \ldots \ldots \overline{V}_m$$

of the speed in the vertic of the " skeleton " of the symbol (in the example in fig 2, it is the letter "a").

<u>Fax Pen</u>

<u>Reconstruction of hand imaging</u> ·

```
#include <stdio.h>
#include <conio.h>
#include <math.h>
#include <string.h>
#include <process.h>
#include <graphics.h>
#include "st.h"
float xmax=913.*5;
float ymax=594.*5;
int per=50;
float v_x[2][1000];
float v_y[2][1000];
int  dotted=0;
unsigned char attr=0;
int cols[5]={8,9,10,12,14};
int extrxy[2][1000];
//calculation of spline function with 2 derivatives and 2 points
float spl(float ,float ,float ,float ,float , float ,float  );
void main (int num_arg, char *arg_st[])
{
// structure of binary file of cubic spline coefficients
   struct stroke
   {
    unsigned x   :13;
    unsigned y   :13;
    signed alf1 :11;
    signed alf2 :11;
    } strk;
    int gdriver = DETECT, gmode, errorcode;
   int j=0;
   int m;
   int i;
   int x;
   FILE *ff;
    float seg,lseg;
    char *exten={".str"};
    int ascii=0;         -

/* test for file extension ".str".If true - it is the ASCII
format *
 * for creating stokes file                                    */
     strlwr(arg_st[1]);
     if ((strstr(arg_st[1],exten))!=NULL) ascii=1;

   if (num_arg<=1) {printf("Requires 1 parameter"); exit(1);}
        i  f  (  ( f f      =  a  s  c  i  i       ?
fopen(arg_st[1],"r"):fopen(arg_st[1],"rb"))==NULL)
   {printf("File not found"); exit(1);}

   registerfarbgidriver(EGAVGA_driver_far);
   registerfarbgifont(sansserif_font_far);
   initgraph(&gdriver, &gmode,"" );
   errorcode = graphresult();
   if (errorcode != grOk)
```

```
{
        printf("Graphics error: %s\n", grapherrormsg(errorcode));
        printf("Press any key to halt:");
        getch();
        exit(1);
}
    setbkcolor (15);
    setcolor(1);
    rectangle(0,0,639,479);
    line(0,35,639,35);
    setfillstyle(1,8);
    bar(1,1,638,34);
    settextstyle(3,0,4);
    setcolor(11);
    outtextxy(142,-5,"The Stroke Interpreter");
/*************************************************/
    if (ascii)
                                                { char
*str1="((((((((((((((((((((((((((((((((((((((((((((((((((((((((
(((((((((((((((((((((((((";
        int res=1;
            while (res!=0)
    { char *str2;
    fscanf(ff,"%78s\n",str2);
    res=strcmp(str1,str2);
    }
    }
    while (1)
    {int temp;
    if (ascii)
    i=fscanf(ff,"%d\n",&temp);
    else
    i=fread(&temp,sizeof(j),1,ff);
    j=temp & 0x1FF;
    attr=temp>>9;
    if (i<=0)
    {
    fclose(ff);
    if (!getch()) getch();
    closegraph();
    exit(1);
    }
    i=0;
    {int vx,vy;
    while( i<j )
        {
    if (ascii)
        {
            fscanf(ff, "%d %d %d
%d\n",&extrxy[0][i],&extrxy[1][i],&vx,&vy);
        v_x[0][i]=((float)vx*5.0/1023.0);
        v_x[1][i]=((float)vy*5.0/1023.0);
        }
    else
        {
        (fread(&strk,sizeof(strk),1,ff));
        extrxy[0][i]=(signed)strk.x;
        extrxy[1][i]=(signed)strk.y;
```

```
    /*
     * preparation from integer to float      *
     *                         */
    v_x[0][i]=(strk.alf1*5.0/1023.0);
    v_x[1][i]=(strk.alf2*5.0/1023.0);
    }
    i++;
    }
  }
 }
j=i;
/*--------------------------------*/
  setcolor(cols[attr&0x07]);
  setlinestyle(0,0,2*((attr&0x08)>>3)+1);
  dotted=(attr&0x10)>>4;
  if(i==1)
      putpixel(extrxy[0][0],extrxy[1][0],cols[attr&7]);
      else
  {
  lseg=seg=0;

    //drawing splines

  for (m=0;m<j-1 ;m++)
    {float y,x1,y1,al1,al2,betc,bets,mods,dlx,dly;
    dlx=extrxy[0][m+1]-extrxy[0][m];
    dly=extrxy[1][m+1]-extrxy[1][m];
    al1=v_x[0][m];
    al2=v_x[1][m];
    mods=sqrt(dlx*dlx+dly*dly);

    x1=extrxy[0][m];
    y1=extrxy[1][m];
    /*------*/
    /*******************************
     *
     * cos and sin of angle between local and global system
     *
     ******************************/
    betc=dlx/mods;
    bets=-dly/mods;
    /*********/
    for(i=0;i<((int)mods+1);i+=2)
    {float x0,y0;
    x=(float)i;
    /*******************************
     *
     *      calculation of local spline function y=f(x) with
parameters:
     *    (start x & y,finish x & y,angels in start & finish,
argument x.
     *
     ******************************/
    y=spl(0.0,0.0,mods,0.0,al2,al1,mods-x);
    /*******************************
     *
     * rotation of local system to global system
     *
     ******************************/
```

```
x0=betc*x-bets*y+(float)extrxy[0][m];
y0=(-bets*x-betc*y+(float)extrxy[1][m]);
if (dotted) {float dx,dy;
    dx=(float)(x0-x1);
    dy=(float)(y0-y1);
    dx*=dx;
    dy*=dy;
    seg=sqrt(dx+dy);
    lseg+=seg;
        }
if (!dotted || (((int)lseg)%(2*per))<per)
   line((float)x0*639/xmax,479-(float)y0*443/ymax,
        (float)x1*639/xmax,479-(float)y1*443/ymax);
x1=x0;y1=y0;
  }
        if (dotted) {float dx,dy;
        dx=(float)(extrxy[0][m+1]-x1);
        dy=(float)(extrxy[1][m+1]-y1);
        dx*=dx;
        dy*=dy;
        seg=sqrt(dx+dy);
        lseg+=seg;
        }
 if (!dotted || (((int)lseg)%(2*per))<per)
     line((float)x1*639/xmax,479-(float)y1*443/ymax,

(float)extrxy[0][m+1]*639/xmax,479-(float)extrxy[1][m+1]*443/y
max);
     }
  }
 i=i;
 }
/*--------------------------------------*/


 }
```

<u>SPLINE RECONSTRUCTION</u> :

Threshold conditions : (margin conditions):

The spline derivatives on the interval [0,11] edges, where l1

module of the vector L1 (see fig 1.)

$$\dot{y}(l_1) = tg\alpha_1$$
$$\dot{y}(0) = tg\alpha_2$$
$$tg\alpha_1, tg\alpha_2 \text{ are calculated as:}$$
$$\cos\alpha_1 = \frac{\overline{V_1}\overline{L_1}}{|\overline{L_1}||\overline{V_1}|}; \quad \sin\alpha_1 = \frac{|[\overline{V_1}\overline{L_1}]|}{|\overline{V_1}||\overline{L_1}|}$$
$$\cos\alpha_2 = \frac{\overline{V_2}\overline{L_1}}{|\overline{V_2}||\overline{L_1}|}; \quad \sin\alpha_2 = \frac{|[\overline{V_2}\overline{L_1}]|}{|\overline{V_2}||\overline{L_1}|}$$
$$tg\alpha_1 = \sin\alpha_1/\cos\alpha_1; \quad tg\alpha_2 = \sin\alpha_2/\cos\alpha_2$$

where [.] vector product defined as :

$$[\overline{VL}] = \begin{pmatrix} i & j & k \\ V_x & V_y & V_z \\ L_x & L_y & L_z \end{pmatrix}$$
$$where V_x, V_y, V_z \quad U \quad L_x, L_y, L_z$$

projections of the vectors

$$\overline{V} \quad u \quad \overline{L}$$

on axes Ox, Oy, Oz according to the significance of the spline

on the interval [01,11] are :

y(0) = y(11) = 0

A spline is defined in the form of :

$$y(x) = a_1 x^3 + a_2 x^2 + a_3 x + a_4$$

where

$$a_1, a_2, a_3, a_4 -$$

are coefficients that are defined by margin conditions.

The equations system relatively unknown values

$$a_i, i = 1 \div 4$$

or

$$y(0) = a_4 = 0$$
$$y(l_1) = a_1 l_1^3 + a_2 l_1^2 + a_3 l_1 + a_4 = 0$$
$$\dot{y}(l_1) = 3 a_1 l_1^2 + 2 a_2 l_1 + a_3 = tg\alpha_1$$
$$\dot{y}(0) = a_3 = tg\alpha_2$$

$$\begin{pmatrix} c_1^3 & l_1^2 \\ 3l_1^2 & 2l_1 \end{pmatrix} \begin{pmatrix} a_1 \\ a_2 \end{pmatrix} = \begin{pmatrix} -tg\alpha_2 l_1 \\ tg\alpha_1 - tg\alpha_2 \end{pmatrix}$$

for

$$a_4 = 0 \quad , \quad a_3 = tg\alpha_2$$

The transformation to a global system is being done in accordance with the expressions:

$$\begin{pmatrix} X \\ Y \end{pmatrix} = \begin{pmatrix} \cos\beta_1 & \sin\beta_1 \\ -\sin\beta_1 & \cos\beta_1 \end{pmatrix} \begin{pmatrix} x \\ y(x) \end{pmatrix}$$

The examples of the different letters reconstruction are given on fig 3.

```c
#include <conio.h>
#include <stdio.h>
#include <math.h>
#include <dos.h>
#include <stdlib.h>
#include <graphics.h>
#include "q_lib.h"
#define DMAX 400

#define T 0.01

struct send_data
    {int period;
     float ampl;
     float incr_acc;
     };

int reconstruct(send_data par[2],int t_count[2],float prev_dif[2])
{
static float px=-10000,py=-10000;
float DIF[2];
int i;
float  acc[4];
float u1;
float u2;
float shift[2];
const float a11=1.071524;
const float a12=0.11965;
const float a21=0.075;
const float a22=-0.22502;
const float b11=13.333333;
const float b12=13.333333;
const float b21=6.666667;
const float b22=6.666667;

  {
    float dx;
    float dy;
    float x,y;
    setcolor(15);

/* Restoration of oscillation signal */
    u1=par[0].ampl*sin(t_count[0]*M_PI/par[0].period);
    u2=par[1].ampl*sin(t_count[1]*M_PI/par[1].period);

/* Restoration of the movement of the center of oscillations */
    DIF[0]=t_count[0]/par[0].period+prev_dif[0];
    DIF[1]=t_count[1]/par[1].period+prev_dif[1];
```

```
/* reconstruction of the position of the pen's tip */
   dx=(a11*u1+a12*u2);
   dy=(a21*u1+a22*u2);
   shift[0] = (b11*DIF[0]+b12*DIF[1]);
   shift[1] = (b21*DIF[0]+b22*DIF[1]);
   if (px > -10000 && py > -10000)
      {
// Addition of the movement of the center of oscillations to obtain XY coordinates.
   x=100+(dx+shift[0])*2;
   y=200+(dy+shift[1])*4;
      if (i)
        {
          line(px,py,x,y);
        }
      // Saving coordinates of previouse point
      px=x;
      py=y;
      }
    else
      {
        px=100+(dx+shift[0])*2;
        py=200+(dy+shift[1])*4;
      }
  }
return 0;
}
```

The reconstruction procedure is performed in two stages:
- Restoring the signals.
- Reconstruction of the position of the pen's tip.

The restoration of the acceleration's signals from the data that was transmited by the pen (T,A,V for every segment) is done according the next formula:

$$u_x(i,t) = u_{x0} + u_{x1} \; ;$$
$$u_{x0} = u_x(i-1, T_{xi-1}) + (V_{xi}/T_{xi}) * t \; ;$$
$$u_{x1} = A_{xi} * SIN \; ((PI/T_{xi}) * t) \; ;$$

$$u_y(i,t) = u_{y0} + u_{y1} \; ;$$
$$u_{y0} = u_y(i-1, T_{yi-1}) + (V_{yi}/T_{yi}) * t \; ;$$
$$u_{y1} = A_{yi} * SIN \; ((PI/T_{yi}) * t) \; ;$$

$$u_z(i,t) = u_{z0} + u_{z1} \; ;$$
$$u_{z0} = u_z(i-1, T_{zi-1}) + (V_{zi}/T_{zi}) * t \; ;$$
$$u_{z1} = A_{zi} * SIN \; ((PI/T_{zi}) * t) \; ;$$

u_x, u_y, u_z are the restored signals of accelerometers.
u_{x0}, u_{y0}, u_{z0} are the restored movement of the center of oscilations.
u_{x1}, u_{y1}, u_{z1} are the restored signal of oscilations.

The reconstruction of the position of the pen's tip in XY plane is done by decomposition of two movements: the movement of the center of oscilations in XY plane (x_0, y_0) and the oscilation movement (contour of written symbol) (x_1, y_1). The calculation of these values is according the next formulas:

$$x_0 = a_{11} * u_{x0} + a_{12} * u_{y0}$$
$$y_0 = a_{21} * u_{x0} + a_{22} * u_{y0}$$

$$x_1 = b_{11} * u_{x1} + b_{12} * u_{y1}$$
$$y_1 = b_{21} * u_{x1} + b_{22} * u_{y1}$$

The parameters a_{ij}, b_{ij} vary from individual to individual and are received as the personal hand imaging characteristics of the writer at the beginning of a session.

C L A I M S

1.   Communication apparatus for hand imaging comprising:
        apparatus for sensing features of hand imaging of an individual which features are highly characteristic of the individual but which also contain information relating to images represented thereby; and
        apparatus for providing a non-individual dependent output indicating the images in response to the sensed features.

2.   Communication apparatus according to claim 1 and wherein said apparatus for sensing features is contained in a handheld housing.

3.   Communication apparatus according to claim 1 and wherein said apparatus for sensing features is contained in a tablet assembly.

4.   Communication apparatus according to claim 1 and also comprising apparatus for communication of the non-individual dependent output.

5.   Communication apparatus according to claim 2 and also comprising apparatus for communication of the non-individual dependent output.

6.   Communication apparatus according to claim 3 and also comprising apparatus for communication of the non-individual

70

dependent output.

7.   Apparatus according to claim 4 and wherein said apparatus for communication is operative to communicate information which can be used to reconstruct an individual's hand imaging style.

8.   Apparatus according to claim 2 and wherein said sensing apparatus does not require a tablet.

9.   Apparatus according to claim 4 and wherein said apparatus for communication comprises a modem.

10.   Apparatus according to claim 4 and wherein said apparatus for communication is operative to communicate in a fax format.

11.   Apparatus according to claim 4 and wherein said apparatus for communication is operative to communicate in a compressed non-raster format.

12.   Apparatus according to claim 4 and wherein said apparatus for communication is operative for wire communication.

13.   Apparatus according to claim 4 and wherein said apparatus for communication is operative for wireless communication.

14.   Apparatus according to any of the preceding claims and

wherein said apparatus for sensing features includes apparatus for sensing the instantaneous angle of motion during hand imaging.

15.   Apparatus according to claim 14 and wherein said apparatus for providing a non-individual dependent output is operative for providing an output indication of strokes generated during hand imaging.

16.   Communication apparatus for hand imaging comprising:

apparatus for sensing features of hand imaging of an individual which features are highly characteristic of the individual but which also contain information relating to images represented thereby; and

apparatus for providing an output indicating the images in response to the sensed features, and wherein

said apparatus for sensing features includes apparatus for sensing the instantaneous angle of motion during hand imaging and providing an output indication of strokes generated thereby.

17.   Apparatus for communicating hand imaging comprising hand-held apparatus for sensing motion and providing an output in a compressed form which can be transmitted by a conventional modem, LAN or other communications medium.

18.   Apparatus according to any of claims 1-13 and 16-17 and also comprising apparatus for receiving communicated stroke

content information and being operative for reconstructing there-
from hand-imaging information.

19.   Apparatus according to claim 14 and also comprising
apparatus for receiving communicated stroke content information
and being operative for reconstructing therefrom hand-imaging
information.

20.   Apparatus according to claim 15 and also comprising
apparatus for receiving communicated stroke content information
and being operative for reconstructing therefrom hand-imaging
information.

21.   Apparatus according to claim 18 and wherein said appa-
ratus for receiving is operative to reconstruct hand-imaging
information in three dimensions.

22.   Apparatus according to claim 19 and wherein said appa-
ratus for receiving is operative to reconstruct hand-imaging
information in three dimensions.

23.   Apparatus according to claim 20 and wherein said appa-
ratus for receiving is operative to reconstruct hand-imaging
information in three dimensions.

24.   Communication apparatus for hand imaging including:
         apparatus for sensing motion during hand imaging and
providing an output indication of stroke content in a compressed

format; and

apparatus for receiving communicated stroke content information and being operative to reconstruct therefrom hand-imaging information.

25.   Apparatus according to claim 24 and wherein said apparatus for receiving is operative to reconstruct hand-imaging information in three dimensions.

26.   A communication method for hand imaging comprising:

sensing features of hand imaging of an individual which features are highly characteristic of the individual but which also contain information relating to images represented thereby; and

providing a non-individual dependent output indicating the images in response to the sensed features.

27.   A communication method for hand imaging comprising:

sensing features of hand imaging of an individual which features are highly characteristic of the individual but which also contain information relating to images represented thereby; and

providing an output indicating the images in response to the sensed features, and wherein

said sensing features includes sensing the instantaneous angle of motion during hand imaging and providing an output indication of strokes generated thereby.

28.   A method for communicating hand imaging comprising
hand-held apparatus for sensing motion and providing an output in
a compressed form which can be transmitted by a conventional
modem, LAN or other communications medium.

29.   A communication method for hand imaging including:
         sensing motion during hand imaging and providing an
output indication of stroke content in a compressed format; and
         receiving communicated stroke content information and
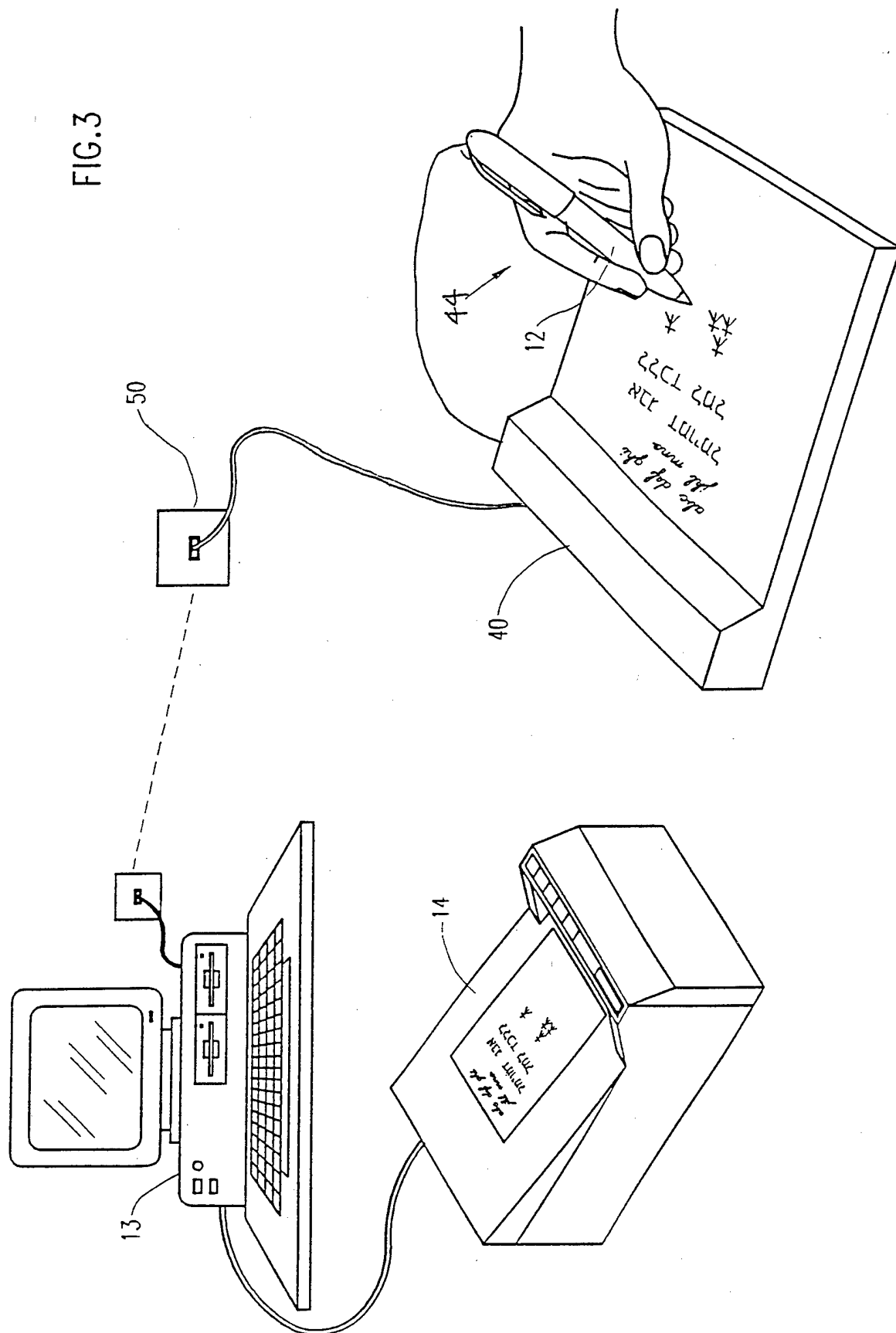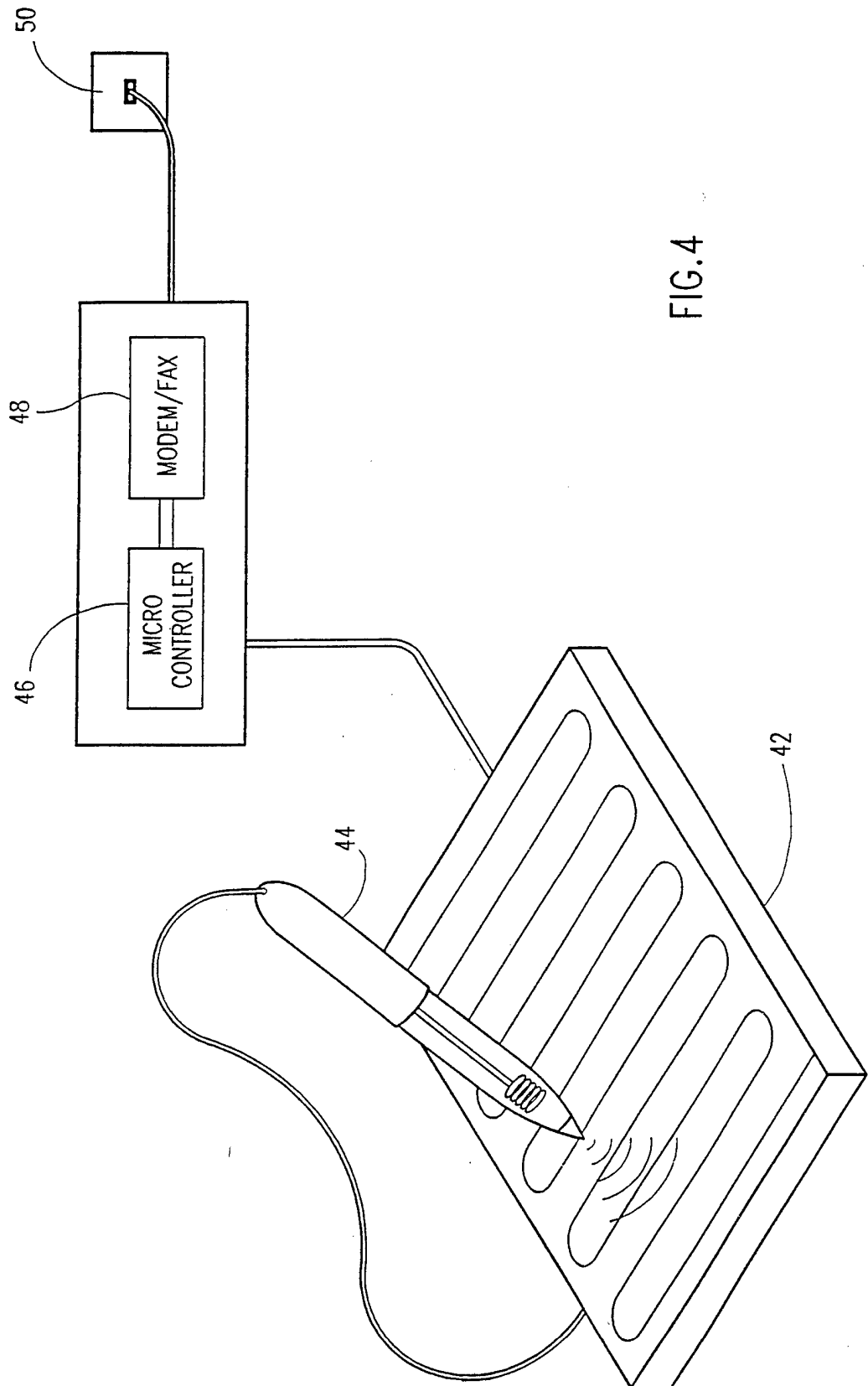reconstructing therefrom hand-imaging information.

FIG.1
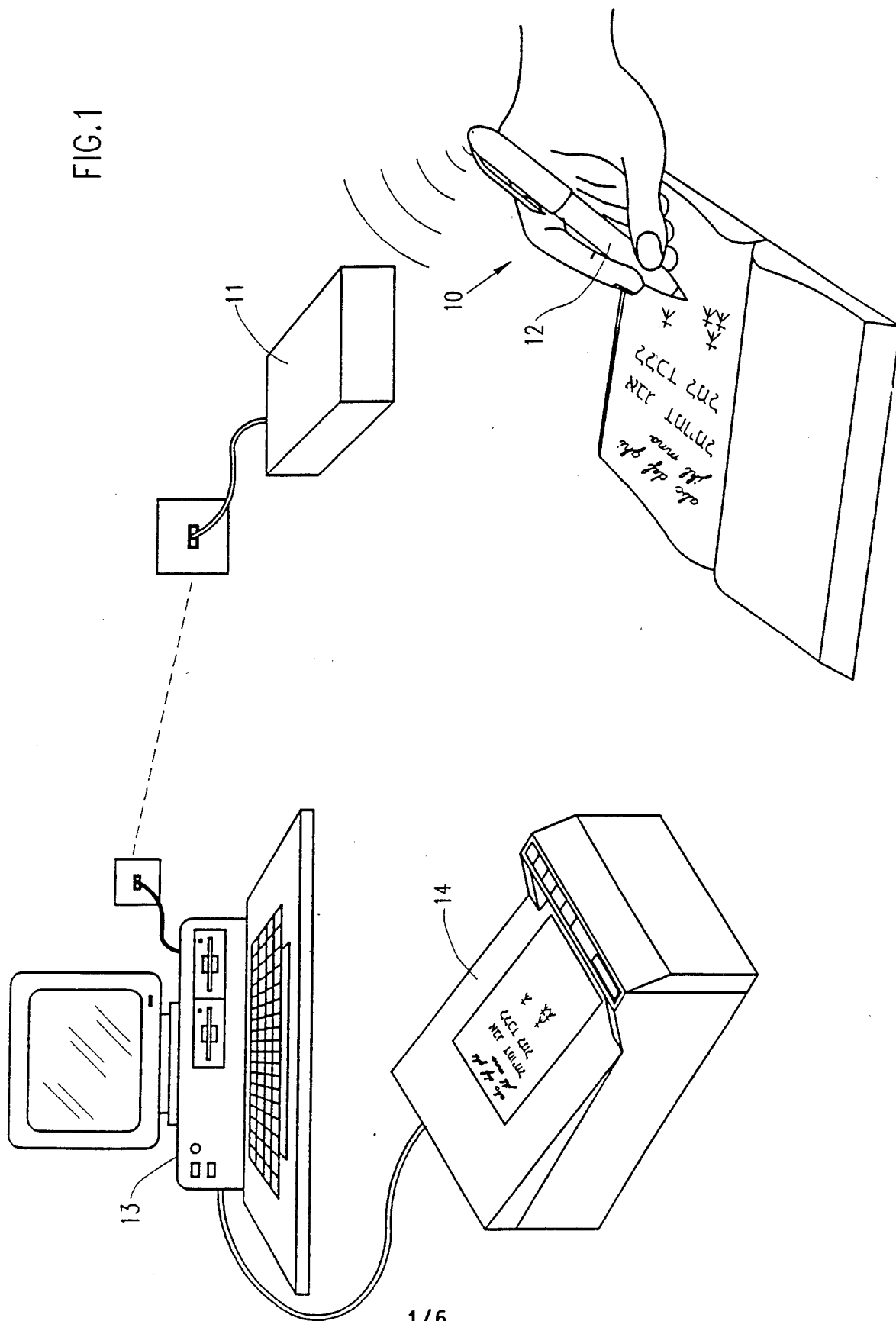
FIG.2
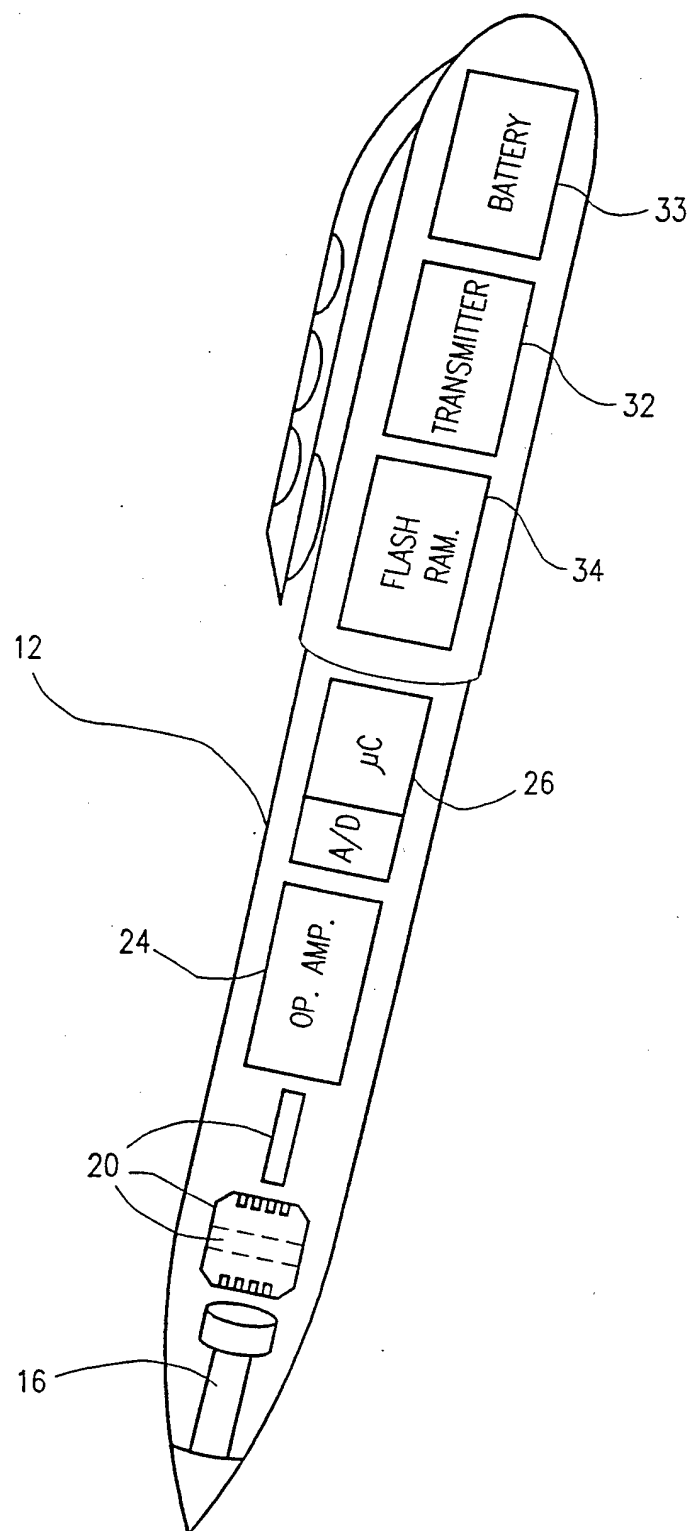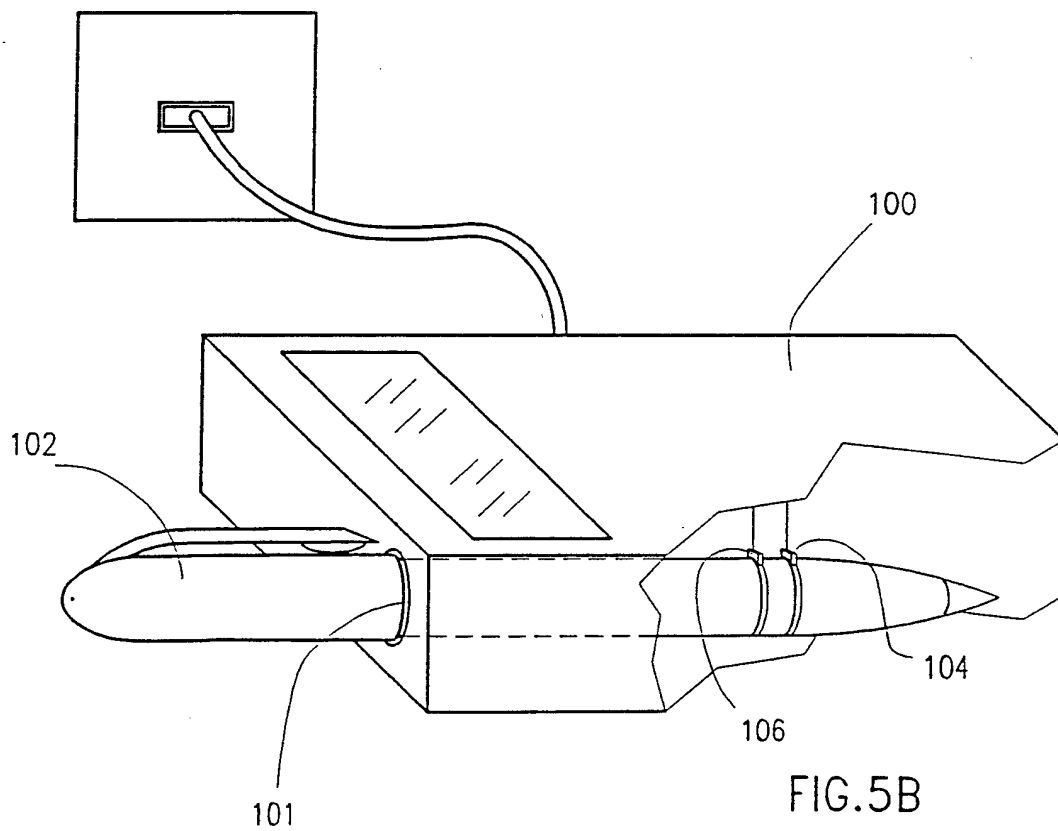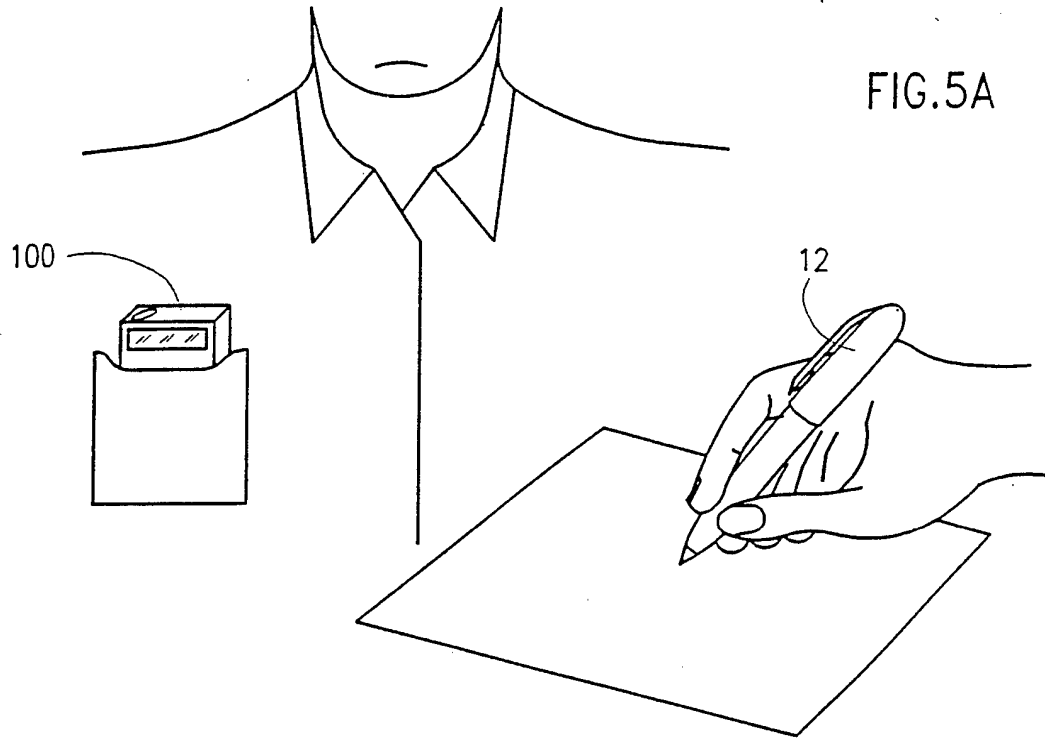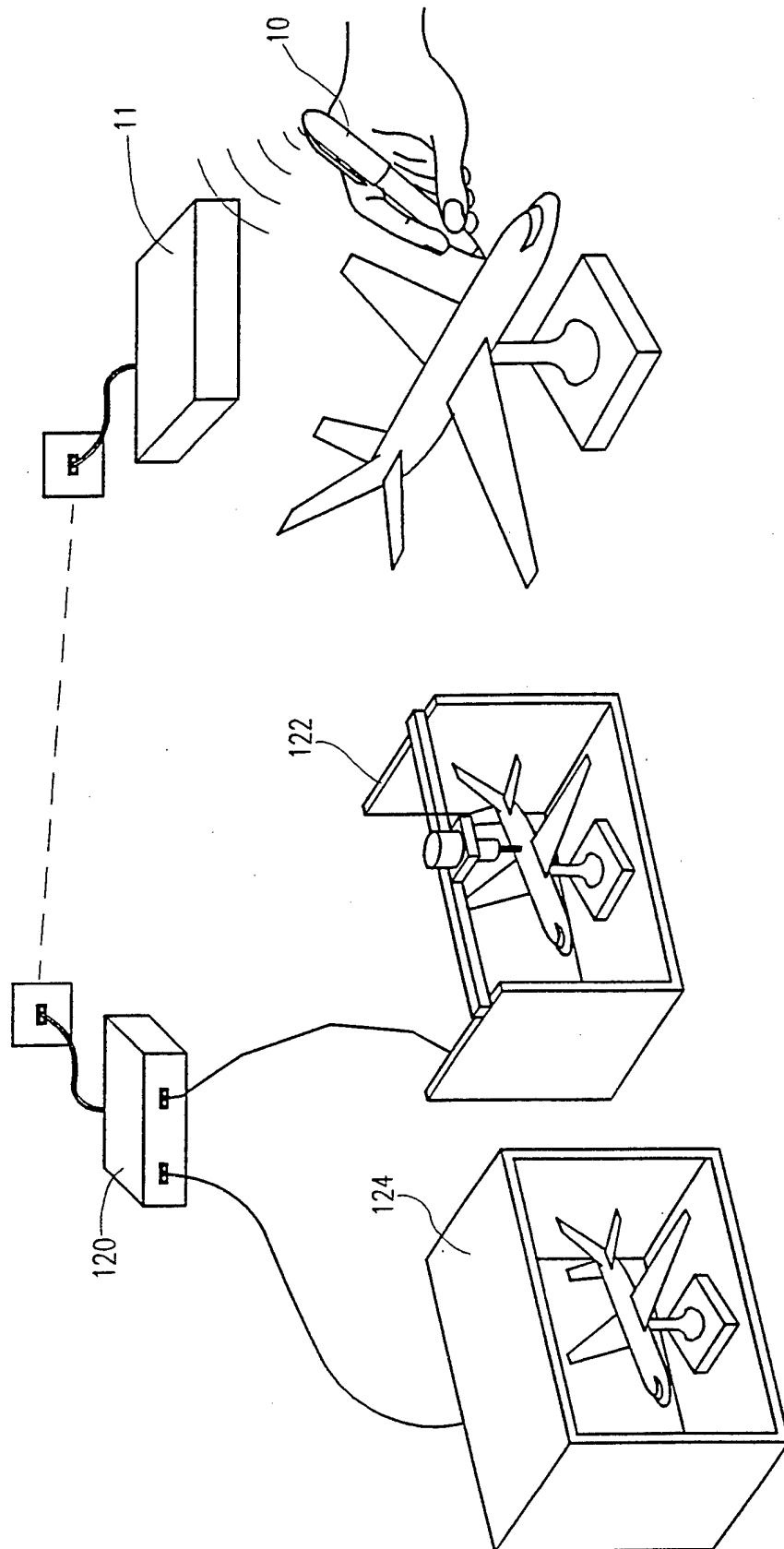
BATTERY — 33

TRANSMITTER — 32

FLASH RAM. — 34

μC — 26

A/D

OP. AMP. — 24

12

20

16

FIG.3

FIG.4

FIG.5A

FIG.5B

FIG.6

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC(5) :G09G 3/02; G08C 21/00
US CL :345/173, 179, 180; 178/18
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 345/156, 157, 173, 179, 180; 178/18, 19.

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US, A, 5,164,585 (LIEU) 17 November 1992 see entire document.	1-7, 11-20, 24-29 -------- 8-10, 21-23.
X	US, A, 5,025,314 (TANG ET AL.) 18 June 1991, figs. 1,2; col. 5; line 64 to col. 6, line 33.	1,16,17,24-29.
Y	US, A, 4,988,981 (ZIMMERMAN ET AL.) 29 January 1991, figs. 1-2, col. 3, lines 13-30.	21-23.
X --- Y	US, A, 4,856,077 (ROTHFJELL) 08 August 1989, figs. 1 and 3.	1-7, 11-20, 24-29 ------- 8-10, 21-23.

| X | Further documents are listed in the continuation of Box C. | ☐ | See patent family annex. |

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be part of particular relevance		
"E"	earlier document published on or after the international filing date	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed	"&"	document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 APRIL 1994	01 JUN 1994
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer Matthew Luu Telephone No. (703) 305-4850

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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X,P	US, A, 5,227,622 (SUZUKI) 13 July 1993, figs. 1-2.	1-29.
X --- Y	US, A, 4,806,707 (LANDMEIER) 21 February 1989, see entire document.	1-7, 11-29 ------ 8-10.
X	US, A, 4,468,694 (EDGAR) 28 August 1984, see entire document.	1-7, 11-29.